Harvard engineering journal

Harvard Engineering Society,
Association of Harvard Engineers

HARVARD ENGINEERING JOURNAL

INDEX TO VOLUME VI

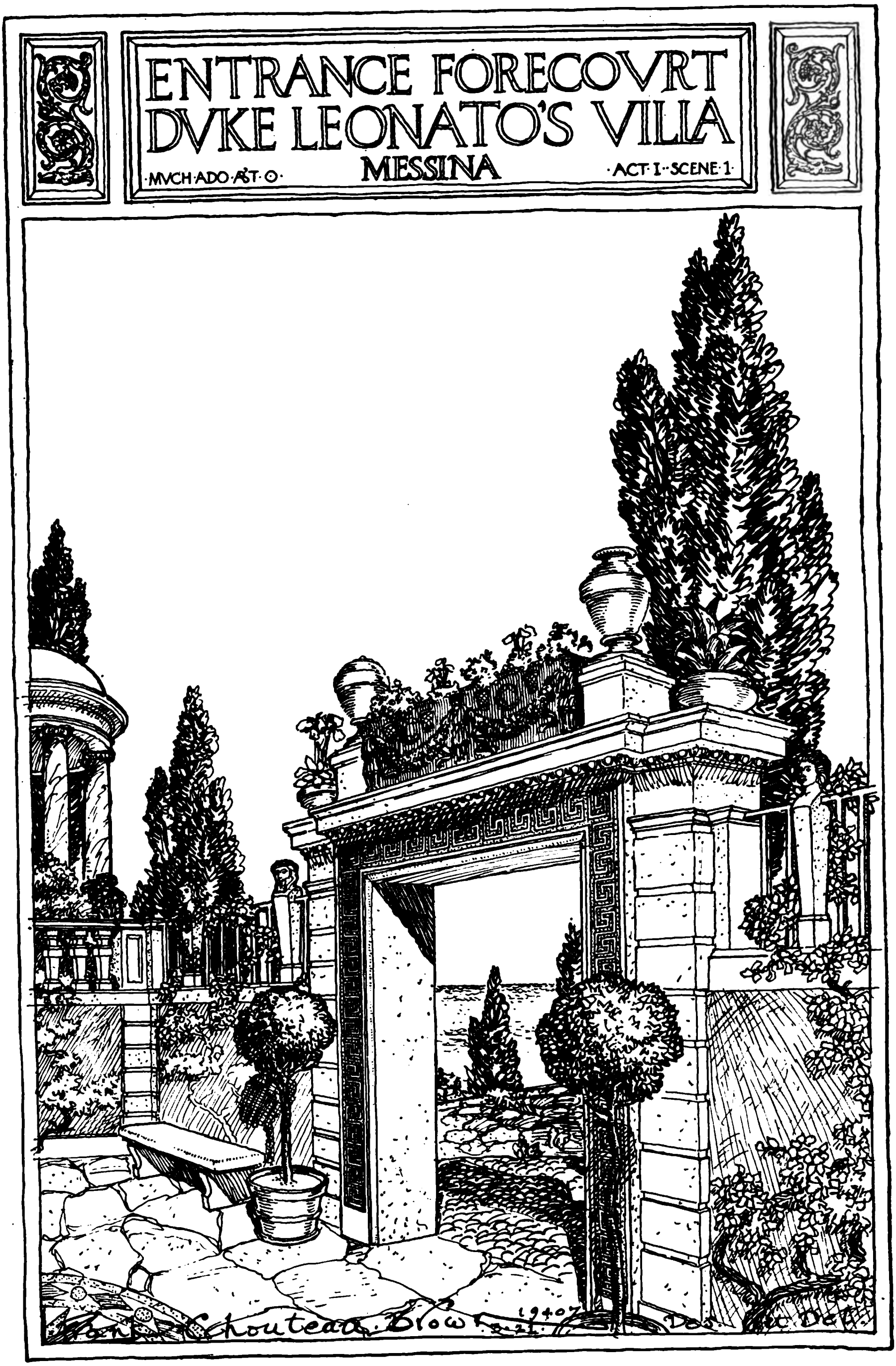
1907-1908

APRIL, 1907

HARVARD ENGINEERING JOURNAL

A QUARTERLY
DEVOTED TO THE INTERESTS OF
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

Vol. VI TABLE OF CONTENTS No. I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HARVARD ENGINEERING JOURNAL

A QUARTERLY

Devoted to the interests of Engineering and Architecture at Harvard University

VOL. VI APRIL, 1907 NO. 1

THE APPLICATION OF THE FAN BLOWER TO MECHANICAL DRAFT.

BY CARL S. DOW,

WITH B. F. STURTEVANT COMPANY.

THE real object of any means of producing draft is the creation of an air current strong enough to pass through the fuel a sufficient quantity of air to furnish oxygen necessary for complete combustion. The essential feature is the overcoming of fuel and boiler resistances, yet it must be remembered that for highest economy and greatest capacity the draft should not be too intense — the difference in pressure above and below the grate should be as slight as will insure the passage of enough air through the fuel to maintain the desired rate of combustion. If too strong, the draft will produce such a velocity of the gases that they will pass over the heating surfaces too rapidly, they will not be evenly distributed and diffused among all parts, especially if water-tube boilers are used. Again, with low velocity of gases, the volume is less which in turn means the admission of a volume of air but slightly in excess of that necessary for combustion.

Conditions thus briefly mentioned can be realized only by a nice adjustment of air flow, a requisite of any draft-creating apparatus, whether natural or mechanical. In the case of a chimney the air is supplied in uncertain quantities; the volume and velocity varying with the temperature of the gases within the chimney, with the thickness of fuel bed, and with atmospheric conditions. This makes it practically impossible to obtain satisfactory control with a chimney.

Of the mechanical means of producing draft, the fan blower has had the widest application except in locomotive practice in which the steam jet is universally employed, not because of economy but on account of its convenience.

Without entering into an extended argument regarding the merits of the fan blower as a draft apparatus, a few general statements may be made:

The blower system is mechanical, it is independent of weather conditions and is effective when most wanted; it can be automatically regulated to maintain constant steam-pressure; it will furnish draft of sufficient intensity for any type of mechanical stoker or for the burning of low grades of fuel. The blower with its driving engine takes up little space, is easily transported, costs only about one-third as much as a chimney, and has a value other than that due to location. With Mechanical Draft it is not difficult to utilize the waste heat by means of an economizer whereas with a chimney the added resistance of the economizer pipes may seriously impair the draft. With balanced-draft systems the fan is necessary, for the chimney does not admit of sufficiently accurate control.

The relative costs of operation depend upon the conditions. If the exhaust from the engine can be utilized the fuel expense is very small — less than the fixed charges on an expensive chimney. In ordinary practice the apparatus seldom requires more than one per cent. of the steam generated.

Forced and Induced Draft.

Since draft is due to a difference in pressure, it is evident that the air flow may be created by increasing the pressure below the grate or by reducing it above. In fact these two methods are employed, and strangely enough the arguments are not overwhelmingly in favor of either. Sometimes one is specified, sometimes the other; under some conditions both are used.

Increasing the pressure below the grate, called forced draft, results in the flow of enough air to maintain the desired rate of combustion and has several advantages over induced draft. It

requires a smaller fan, for a given weight of air at atmospheric pressure and temperature occupies less volume than when at the temperature of the stack. The fan blower and its engine can readily be placed on the fire-room floor where they will receive attention, and the bearings are subjected to normal conditions only. It is claimed that the greater pressure within the furnace causes a rush of gas and smoke into the fire room whenever the furnace doors are opened, but this can be overcome by so arranging the dampers in the flue leading to the stack that the entire

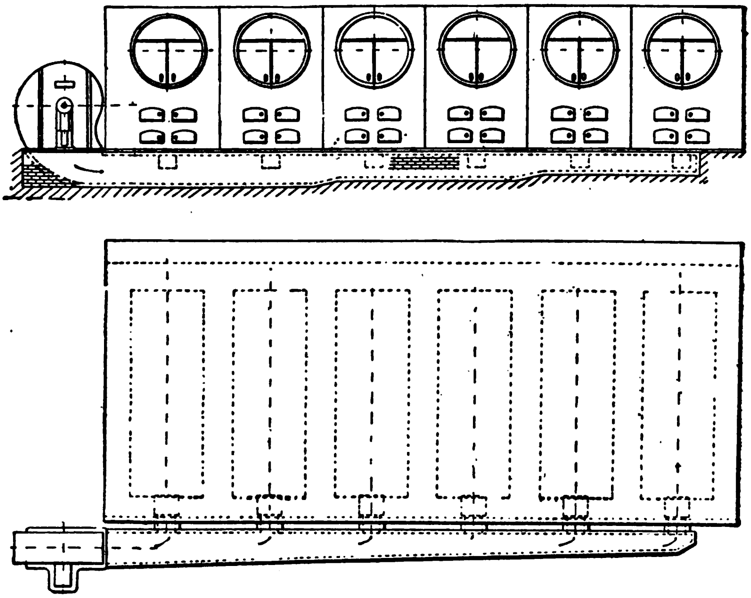

FIG. 1.

volume will pass up the flue by natural draft even when the fan is at maximum speed. The speed of the fan, not the position of the damper determines the intensity of the draft. Another method is to reduce the speed of the fan while firing.

In any system of forced draft the air is forced under the grate by means of a centrifugal fan blower delivering air to a duct in front of the boilers and leading to the ash pits as shown in Fig. 1. Each branch duct conducting the air to its ash pit is equipped with an ash-pit damper for regulating the flow. This scheme is

often followed in changing from chimney to forced draft or in installing a fan as an adjunct to the chimney.

With a new plant, a hollow bridge wall is often utilized as the duct, in which case the air from the fan enters each ash pit through a bridge-wall damper, the general plan being shown in Fig. 2.

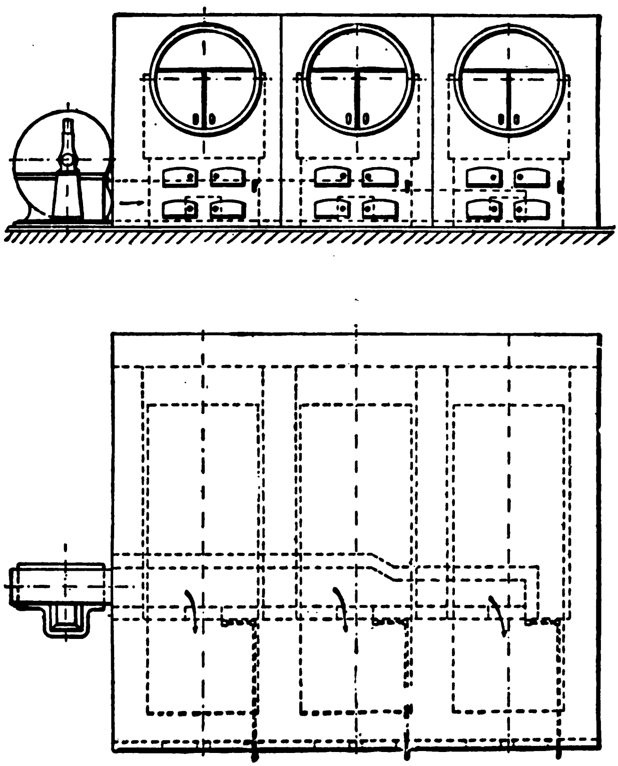

Fig. 2.

Forced draft requires simply a steel stack of sufficient height to discharge the gases above the boiler house roof, the height depending upon that of the adjacent buildings.

Another system used primarily in marine boiler plants is called the "closed fire-room method." The entire fire-room has an air pressure slightly in excess of atmospheric air, thus causing the flow through the fuel bed. The air leakage being outward insures

excellent ventilation of the fire-room and the pressure in the room absolutely prevents a rush of gases from the fire doors.

In the induced system, shown in Fig. 3, the fan blower is placed between the smoke flue of the boilers and the stack; it creates

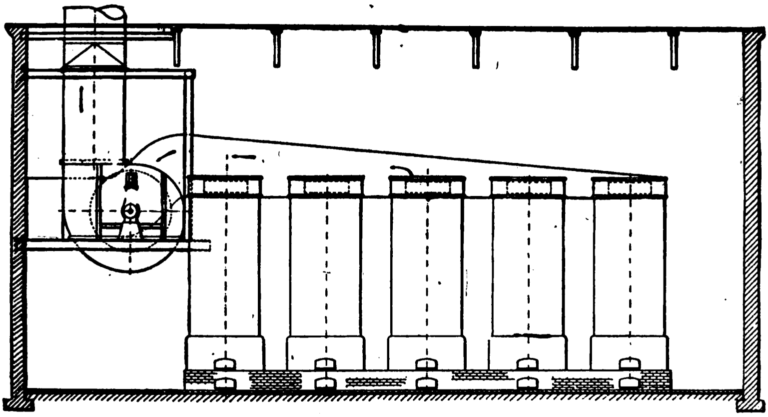

FIG. 3.

draft by exhausting the gases from the boiler uptakes and conducting them to the stack. The action is more nearly like that of a chimney than in the case of forced draft. The advantages of this system are the absence of outward leakage in the fire-room, which may cause the gases to escape into the boiler room, and the more even distribution of draft over the fuel bed preventing the tendency of the fire to burn through in spots. Among the disadvantages may be mentioned the larger fan required, the inaccessibility of the draft apparatus, and the necessity of having this apparatus subjected to a temperature of about 500° F. which calls for water-cooled bearings for the fan. The driving engine also is so elevated and in such a heated atmosphere that it is liable to be neglected.

The induced system is usually preferred to forced draft if an economizer is to be installed, for the cooling of the gases by the economizer reduces the volume and lessens the heat at the bearings of the apparatus. With this system a by-pass flue should always be provided, for with a steam-driven fan some draft is necessary before there is sufficient steam pressure to operate the fan engine.

Fans.

The form of blower now used for supplying air to boilers is of the centrifugal type, and built of steel plate. Since experience shows that under most circumstances the draft should not exceed 1 inch of water, cast-iron fans are seldom used, with the possible exception of cases of mechanical draft in which the stokers of the underfeed types are installed.

The fan used for producing mechanical draft should be a volume fan, rather than a pressure fan, and may be either a blower or an exhauster. In internal construction there is no difference between

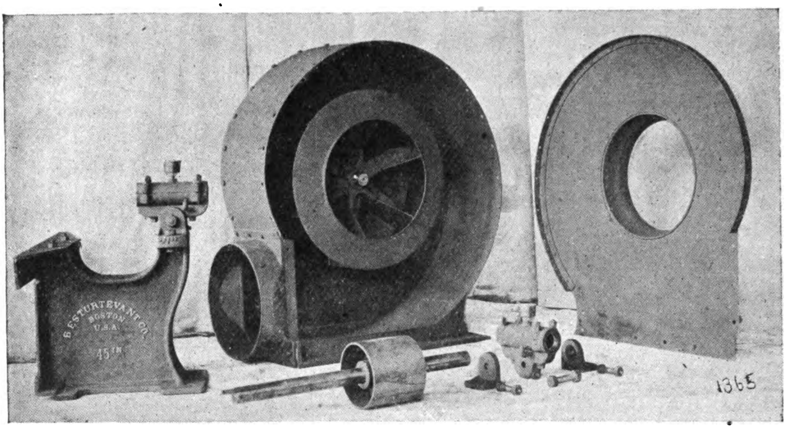

Fig. 4.— Details of Steel Plate Fan.

the blower and the exhauster but the blower has two inlets, one upon each side of the casing and through which the shaft passes. The exhauster, on the other hand, has one of these openings closed by a plate to prevent the passage of air. The inlet of an exhauster is on the side farthest from the pulley, engine, or motor by which the fan is driven, so that in the case of induced draft the smoke and hot gases need not pass over the driving mechanism. For both forms of forced draft the blower should be used, while induced draft necessitates the exhauster so that it may draw the gas through the one opening and force it to the stack.

Blowers and exhausters are made to discharge in any direction to suit the lay-out of piping, the bottom horizontal being the most

common. Cased fans are also called "right-hand" and "left-hand," according to the location of the pulley or driving motor with respect to the outlet. When one stands facing the outlet and the pulley or driving motor is on the right-hand side, the fan is called a right-hand fan. A steel-plate fan having a free, unobstructed opening at the inlet, is built as what is known as an "overhung-wheel" fan, that is, the two bearings that support the pulley are placed upon the same side of the fan casing so that the wheel is overhung on the shaft and does not need a support at that end. (See Fig. 4.) This is quite an advantage in the case of a fan for

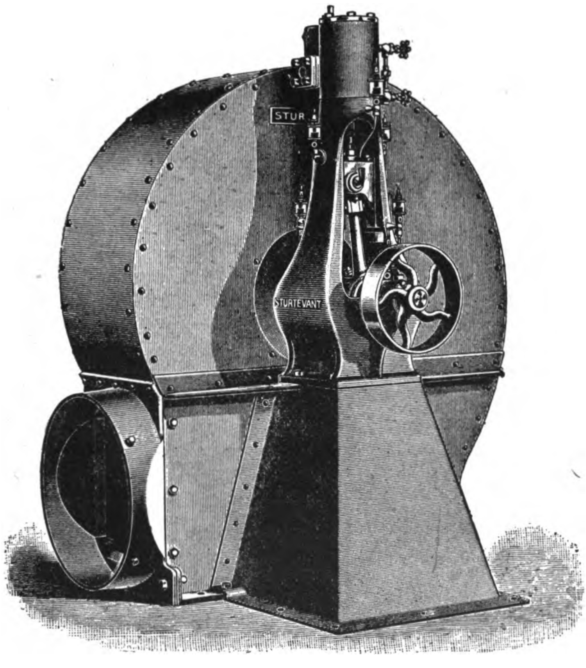

FIG. 5.— STEEL PLATE STEAM FAN.

induced draft, for the hot gases as they enter do not come in contact with the bearings.

The blower or exhauster as commonly constructed for mechanical draft consists of a steel-plate casing of the form shown in Fig. 5. The fan wheel revolving in this casing draws in air at the

inlets, which are concentric with the shaft. The rapid revolution of the wheel gives the air a rapid motion and discharges it centrifugally from the tips of the blades. The air delivered radially from the periphery is forced from the outlet which is tangential. The casing is usually built up of steel plate cut to the proper shape and riveted or bolted to bars of T section, or to angle irons. The fan wheel, which is enclosed within this shell, is of the form shown in Fig. 6. It consists of a series of T-shaped arms of steel cast

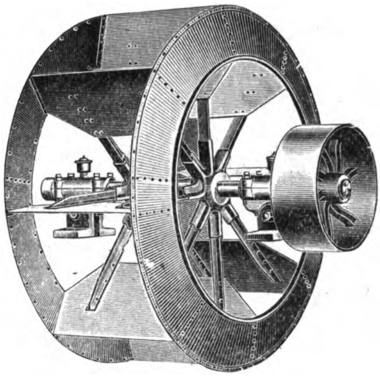

FIG. 6.

into the hub, which is of cast iron. To these steel arms are fastened plates which form the blades, vanes, or floats of the fan, and these blades are in turn secured to the reinforcing rings as shown. Through the center of the hub passes the steel shaft to which the hub is keyed. The shaft is supported in bearings which are so placed that the axis of the shaft coincides with the center of the scroll of the blower. The fan wheel is carefully balanced so that it will run true even at high speed.

Fig. 7 is a fan of the type called a three-quarter housing; and unlike the exhauster shown previously, a part of the casing is below the floor. The upper part is of steel plate, while the lower part may be of steel plate as shown, or of brick or concrete. Large fans are often made of this type to give less height above the floor. In making fans, whether blowers or exhausters, it is customary to use long bearings so that the pressure per square inch will be

very low, thus giving an extremely long life to the bearing and reducing the friction and wear to a minimum.

The existing conditions always determine the most economical or the most convenient method of driving blowers and exhausters. Some fans are arranged for the pulley drive, and the belt may be run from the pulley to the band wheel of an independent engine, to a line shaft, or to an electric motor. Another method, and one most commonly used in power plants, is to place a small steam

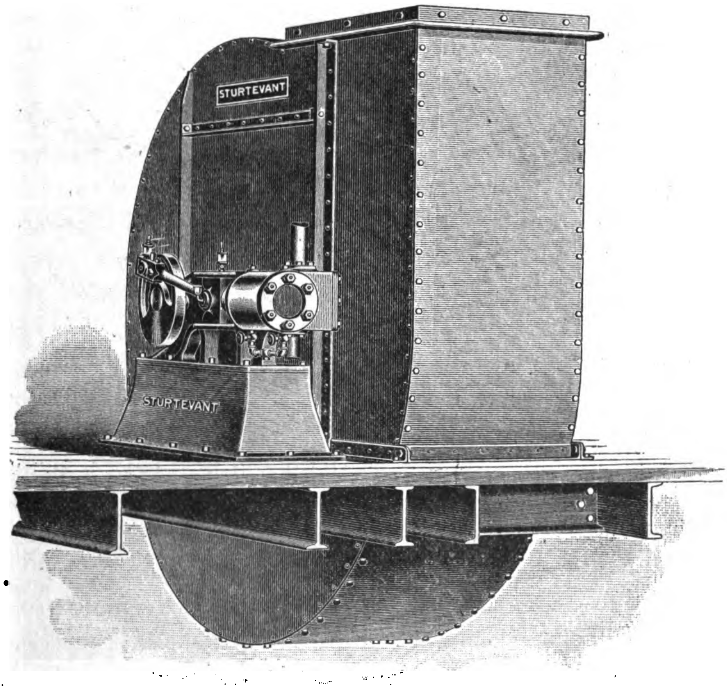

FIG. 7. — STEEL PLATE STEAM FAN.
(Three-quarter housing type with steel plate bottom.)

engine on the shaft and support it by a cast-iron or steel-plate base, as shown in Figs. 5 and 7. The direct-connected steam engine is especially advantageous in the power plant, for the fan may be started just as soon as there is sufficient steam to move the engine, which may be long before the main engine (and there-

fore the line shaft) can be operated. In most plants it is considered very desirable that the fan be provided with means of driving which is independent of all other sources of power.

An exhauster made especially for induced-draft apparatus has an inlet connection through which the hot gas passes; the shaft carrying the fan wheel passing through the chamber, and to the bearing, which is upon the outside. By thus extending the shaft through the connection and supporting it by a special water-cooled box the bearing is kept perfectly cool even when the fan is handling the hot gases from the boiler. It may be driven by a direct-connected engine, or by a belt.

To make draft apparatus certain and positive in action, two fans are often installed, either of which may be disconnected. The two fans are of the same size and set side by side; when the two shafts are coupled together the fans run in unison. It is customary to install the fans of such size that one will take care of average load, while both may be used for maximum duty.

Selection of Fan for Plant.

The size of the fan to be installed in any power plant depends upon the amount of air necessary for combustion. If a chimney is to be used in conjunction with the fan, its action must, of course, be allowed for, but in most cases the mechanical draft apparatus does the entire work. The great variety of conditions under which fans are operated, and the resistances of piping, fuel, and boiler tubes are so uncertain and so difficult of calculation, that it is far better to submit to a company making fans a complete statement of the existing conditions and then rely upon their experience to select the fan that can be guaranteed to do the work. As all such companies are glad to do this engineering, it is not only a waste of time, but a chance to make a grave mistake if one unfamiliar with fans attempts to select the proper size. Since the pressure seldom, if ever, exceeds one ounce, or an ounce and a half, per square inch, the type of fan is practically settled at the outset, that is, for a large volume at this low pressure, as has already been stated, the steel-plate fan is suitable. The only question is that of size and speed.

We know that the object of the mechanical-draft apparatus is to supply air for combustion, therefore the first question to be decided is how much air must be supplied. Suppose the plant is of 3000 boiler horse power. We know that a horse power is equivalent to about $34\frac{1}{2}$ pounds of steam; therefore the total amount of steam will be about 103,500 pounds. The coal burned varies considerably, according to the kind and size of the pieces, but we may assume that one pound of coal will evaporate 8 pounds of water. Therefore the plant will need a little over 12,900 pounds of coal per hour. From a study of combustion we find that about 12.5 pounds of air are theoretically necessary per pound of coal, but as more air must be supplied than is necessary, it is customary to allow from 18 to 23 pounds of air. If we assume 18 pounds we can readily find the weight per cubic foot, since we know that at 60° Fahr. a cubic foot of air weighs practically .76 pound. Thus about 235 cubic feet of air are necessary per pound of coal; for 23 pounds 300 cubic feet will be required. In order that the fan may be sufficiently large it is customary among engineers to allow for 300 cubic feet of air per pound of fuel. Then with the plant in question the total volume of air per hour will be $12{,}900 \times 300 = 3{,}870{,}000$ cubic feet, or 64,500 cubic feet per minute. The volume per minute should be the one used in calculations, for it is upon this basis that all fan tables are made.

This brief calculation gives us an idea of the method of calculation, and of the size of fan that must be used in this case, but before actually selecting the fan many other considerations must be borne in mind. The cost of a fan is one of the items usually to be considered, and this cost may be divided into two parts, the first cost and the running expense. It is unwise to give too much prominence to the first cost of a fan unless one has also carefully considered the running expense. For instance, if the fan chosen is too small for the work, the first cost will be low, but the expense of operating will be much greater than is necessary. It is a fundamental principal that the fan selected should always be large enough to supply ample volume of air without too much pressure. The amount of energy necessary to move a given volume of air is equal to the product of the distance the air is moved and the

total resistance which is overcome. Since the pressure per square inch and the area are easily found, the total pressure multiplied by the velocity, or the total number of foot pounds of energy, is a simple problem. But this power is theoretical and in practice cannot be relied upon to give accurate results.

A mathematical consideration of the subject will show that the power required to drive a fan increases as the cube of its speed. This fact alone shows the necessity of selecting a fan that need not run at high speed. The volume delivered by a fan is directly proportional to the speed, and is also directly proportional to the width of the fan wheel, if of stated speed and diameter.

When a fan forces air through a pipe at a given pressure, the fan wheel must create a total pressure above the atmosphere which shall be sufficient to produce the desired velocity and also overcome the frictional resistances of the fan casing and the delivery pipe. The fan wheel diameter and circumference being known, the velocity of the fan tips is easily found, since it is simply the circumference multiplied by the number of revolutions per minute. This velocity is practically the same as the velocity of air flow, provided the outlet is of the proper shape and of size that is within the capacity of the fan.

It can be shown that the volume varies directly as the speed; pressure varies directly as the square of the speed; and the horse power varies directly as the cube of the speed.

In selecting a fan these facts should be borne in mind. Although it appears to be a very simple matter to secure increased volume by running a fan at higher speed, yet this condition will add greatly to the cost of operation, for with an increase in speed the power increases rapidly. In the design of a wheel it is necessary to make a peripheral speed such as to create the desired pressure, and then make its width to provide a given volume, but for most work it is impracticable to make the width much greater than the radius of the fan wheel. If too narrow a wheel is used, it may be necessary to run the fan at a higher velocity to obtain the given volume, and this operation will increase the pressure above that required, and consume more power than is necessary.

The method of driving a fan is also an important factor, for with

the independent steam engine, which is the usual method in power plants, the number of revolutions of the fan must be about the same as the most economical speed of the engine. Theoretically the volumetric capacity of a fan depends upon its dimensions and upon the speed, but in actual practice the amount of air delivered depends also upon the size and resistances of the passages through which the air is conducted, and upon the dimensions of the fan case.

On account of the great difference of conditions under which fans are operated, it has been the custom to determine what is commonly known as the "square inches of blast." This theoretical area is the limit of the fan capacity to maintain the given pressure. It is a theoretical area which if increased will cause a reduction in pressure, but if it is decreased the pressure will remain the same. The "square inches of blast" may be determined approximately by the formula.

$$\text{Capacity area, or square inches of blast,} = \frac{D\,W}{X}$$

in which D equals the diameter of the fan wheel in inches, W equals the width of the fan wheel at the circumference in inches, and X equals a constant determined by experiment, and which is generally considered to be 3. This theoretical area is simply the capacity area, and is neither the size of the inlet nor the size of the outlet. The area of the outlet which varies with the type of fan is always much greater than the "square inches of blast," in fact it is usually over 100 per cent. greater. By thus increasing the "square inches of blast," to the size of the actual outlet of a fan, the pressure becomes lower and the volume discharged becomes greater.

The reason for using an outlet so much larger than the theoretical "square inches of blast" is due entirely to the frictional loss resulting from moving air in pipes. If the actual outlet were as small as the theoretical blast area, and the pipe were 100 feet long, the frictional loss would be excessive. To overcome this and yet get the desired result at the farther end of the pipe (as for instance beneath the grate of a boiler furnace) the outlet area is increased, which permits of a much larger pipe for conducting the air. The result is that at the farther end of the pipe there is much less pres-

sure, due to the larger area, but the transmission loss has been small. If, now, the area at the farther end of the pipe be contracted, or, what is equivalent, if the air meets the resistance of the fuel on the grate, the pressure will increase to about the same value it had when it left the fan tips; by using the large pipe much of the loss due to transmission has been saved.

The accompanying table, compiled by the B. F. Sturtevant Company, gives the number of revolutions of a fan wheel of a

Revolutions of Fan Wheel of Given Diameter

Necessary to Maintain a Given Pressure Over an Area which is within the Capacity of the Fan.

Diameter of Fan Wheel, in Feet.	Pressure, in Ounces per Square Inch.												
	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$
1	582	823	1,007	1,163	1,300	1,423	1,537	1,643	1,742	1,836	1,925	2,010	2,170
$1\frac{1}{4}$	466	658	806	930	1,040	1,139	1,230	1,314	1,394	1,469	1,540	1,608	1,736
$1\frac{1}{2}$	388	549	672	775	867	949	1,025	1,095	1,162	1,224	1,284	1,340	1,447
$1\frac{3}{4}$	333	470	576	665	743	813	878	938	996	1,049	1,100	1,149	1,240
2	291	411	504	582	650	712	769	822	871	918	963	1,005	1,085
$2\frac{1}{4}$	259	366	448	517	578	633	683	730	774	816	856	893	964
$2\frac{1}{2}$	233	329	403	465	520	570	615	657	697	734	770	804	868
$2\frac{3}{4}$	212	300	366	423	473	518	559	597	634	668	700	731	789
3	194	274	336	388	433	475	513	548	581	612	642	670	723
$3\frac{1}{2}$	166	235	288	332	372	407	439	469	498	525	550	574	620
4	146	206	252	291	325	356	384	411	436	459	481	502	543
$4\frac{1}{2}$	129	183	224	258	289	316	342	365	387	408	428	447	482
5	116	164	202	232	260	285	308	329	349	367	385	402	434
$5\frac{1}{2}$	106	149	183	211	236	259	280	299	317	334	350	366	395
6	97	137	168	194	217	238	256	274	290	306	321	335	362
$6\frac{1}{2}$	90	126	155	179	200	219	236	253	268	282	296	309	334
7	83	117	144	166	186	203	220	235	249	262	275	287	310
$7\frac{1}{2}$	78	110	135	155	173	190	204	219	232	245	257	268	289
8	73	103	126	146	163	178	192	205	218	230	241	251	271
$8\frac{1}{2}$	69	97	119	137	153	167	181	194	205	216	226	236	255
9	65	92	112	129	144	158	171	183	194	204	214	223	241
$9\frac{1}{2}$	61	87	106	123	137	149	162	173	183	193	203	212	228
10	58	82	101	116	130	142	154	164	174	184	193	201	217
11	53	75	92	106	118	129	140	150	158	167	175	183	197
12	49	69	84	97	108	119	128	137	145	153	160	168	181
13	45	63	78	90	100	110	116	126	130	141	148	155	167
14	42	59	72	83	93	102	110	117	124	131	138	144	155
15	39	55	67	78	87	95	102	110	116	122	128	134	145

given diameter necessary to produce a given pressure. The limits given, both as to pressure and fan diameter, are such as are found in mechanical draft equipment. The size of a fan for

induced draft must evidently be considerably greater than for forced draft, due to the greater volume. In fact, under ordinary conditions, without an economizer, the fan for induced draft should have practically double the capacity of a fan for forced draft. If, however, an economizer has been installed and the gases cooled to the usual working conditions of an economizer, that is, cooled through probably 250°, the fan need be increased in size only 50 per cent. But it is customary to make no reduction, so that the fan will be large enough if the economizer is cut out of service.

One of the conditions having a marked influence on the amount of air handled by the induced draft equipment is the leakage through the boiler setting. A leaky setting necessitates a larger fan, for the fan must handle all the air that leaks in, in addition to taking care of the hot gases. This leakage is of course difficult of determination, and consequently but little can be said here regarding the extra burden thrown upon the fan.

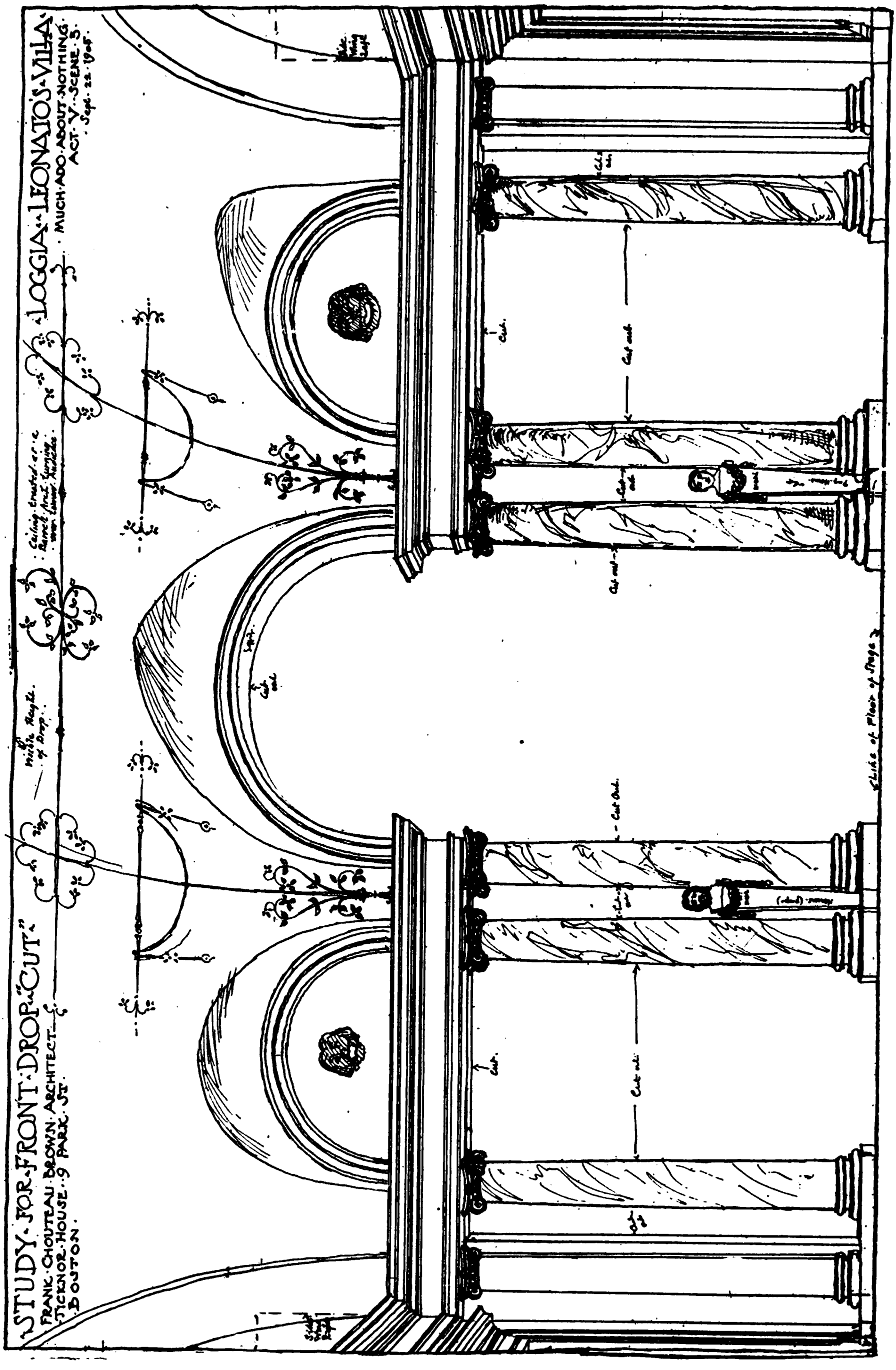
STUDY·FOR·FRONT·DROP·"CUT"
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FIG. 11

MODERN STAGE SETTINGS, SHAKESPEARIAN AND OTHERWISE*

with Especial Reference to a Production of "Much Ado about Nothing" as given at the Castle Square Theatre, Boston, with scenery designed

BY FRANK CHOUTEAU BROWN, ARCHITECT.

UNLIKE many of his other plays, in the comedy of "Much Ado about Nothing," Shakespeare has apparently been at some pains to definitely locate the action in Messina, an actual sea-port town on the island of Sicily that has retained its commercial importance even unto this day. It may be that, at the date of the composition of the play, the name of this city — as was the case with "Venice" — possessed some especial and sympathetic meaning for the Englishman of his time, or it may well be it was the mere suggestive euphony latent in its syllables that alone finally determined its selection and retention by Shakespeare. While much of the material of "Much Ado" is original with the dramatist, it is of course recognized that he may have obtained a part of the skeleton of the structure from some one of the several Italian *novelle* — perhaps preferably that version found in Matteo Bandello — to which it possesses an undisguised resemblance.

Certainly the place-location bears no particular relation to the development of the story; though — as invariably happens with Shakespeare — both it and its surroundings proffer to the scene-designer a most ideally picturesque and distinctive background for the progress of the play. The period is less exactly stated and, for the purpose of the story, equally unimportant; but from the various references made in the first scenes, a fairly definite date may be approximated, and so it is generally considered that the play could have occurred in some of the years following soon after the Battle of Pavia (1525) — certainly between then and the end of the century.

* This is the second of three articles by the same writer dealing with the above general subject. The first section was published in the January number of this Magazine. The third (to be published in June) will deal with the technical side of Scene designing.

This apparently unnecessary definiteness in placing the story in a particular part of Sicily has indeed been the cause of some trouble to those persons of so literal a mind as to find it necessary to identify the precise war that would have been the occasion of bringing these foreigners naturally upon the island. For those matter-of-fact individuals whose constitutions first demand such a tangible groundwork before being able to allow their imagination free play, it may be said that it is quite possible that the Spaniards and Italians appearing at Leonato's Court are here seen returning to Sicily from some of the many small wars that were intermittently being waged over Europe — and especially in Italy — at about this time, continuing through the lives of Charles the Fifth and Francis the First. Such events as here occur might have happened at any time up to, or near the very end of, the reigns of these volatile sovereigns. At any rate, it is certain that the scene may be laid safely within the period of the Renaissance; and more probably during the middle or end of the 16th century. It is this period then,—without undue pedanticism or over-nice particularity — that the settings for the Castle Square version were designed to generally reproduce.

Not only does the island of Sicily proffer a setting in itself naturally pictorial but, in addition, its architectural history is sufficiently singular to make it perhaps illuminative to pause for brief reference to it here, in order to comprehend the peculiar admixture of architectural styles that may have been extant in the city of Messina at the date of the play. The earliest well-preserved architectural ruins on the island are Greek Doric; while many of the now existing buildings were evidently remainders of succeeding, or sometimes even earlier periods, when the influence of Carthage, of Rome, Byzantium, Arabia, Normandy and mediæval Italy had been, each in its turn, supreme. Romanesque, Gothic and Renaissance structures are all extant in picturesque combination. Yet, even in the 12th and 13th centuries, the Sicilian Gothic differed, in many of its essentials, from the Italian Gothic of the mainland. Occasionally architecture of a Lombardic or even Provençal suggestion will be found, although these bits are more rare; except upon the very northern part of the island, where Messina lies.

The mediæval architecture of this city, Messina, is, then, more Romanesque; and contains less of the Greek spirit that has survived through many vicissitudes in the other — especially the eastern and southern — portions of the island. Messina is, too, the largest important port near to Italy. It is the cathedral town, with a church built upon the Basilican type; somewhat like the far better known one at Monreale. The buildings, whether early or late, were ordinarily constructed of white stone and plaster and appear much whiter even than they really are, through the powerful contrast afforded by the dark green of the wooded hills which form the background to the city on one side, and the deep blue of the Mediterranean that surrounds it upon the other.

So the buildings in Messina may be part Oriental, part Byzantine, part Romanesque, and part Classic and Renaissance, set within stimulatingly beautiful surroundings of mountain and water, and a vegetation almost tropical in its luxuriance and type forms; the whole conforming — as do the suggested settings to all of Shakespeare's stories — admirably and effectively toward making an ideally picturesque and appropriate background for the progress of the play.

The scenes called for by the version prepared for this production were, in order, as follows:

Act.	I.	The Courtyard of Leonato's House.	(full stage)
"	II.	Leonato's Garden. (evening)	" "
"	III.	sc 1. " " (morning)	" "
		" 2. " " (afternoon)	" "
		" 3. Messina. A Street. (midnight)	(shallow scene)
"	IV.	" 1. A Church in Messina.	(full stage)
		" 2. A Prison. (Shallow, only occupying centre of stage)	
"	V.	" 1. Courtyard before Leonato's House.	(full stage)
		" 2. Before Leonato's Monument.	(very shallow)
		" 3. Leonato's House. The Terrace.	(simple and deep)

Perhaps no other Shakespearian play that is so often presented, appears with such a variety in the location, placing and arrangement of the various scenes. The present version confines itself to

two well-defined localities; the city of Messina, and the villa of Duke Leonato; the latter placed upon the hillside overlooking the bay and the city below. The action occupies four days' time and all passes within seven scenes, and although, only one "comes back," or repeats, as they would say behind the scenes, several are used more than once. Those occurring in Leonato's palace include the courtyard, in Act I and the first scene in Act V; the garden of Act II and the first two scenes in Act III, and finally, a loggia and terrace looking out upon the water — for the final scene: in the City; first, a street — forming the last scene in Act III; second, the interior of a church — the first scene in the IVth act; and third, the second scene in the same act, a prison. In the last act the second scene is played before Hero's monument, the location of which is somewhat indefinite; but it has been assumed to be placed in the graveyard or grounds surrounding the church, and to be actually the family tomb of Leonato.

In other productions of the play, the various scenes have been placed in an orchard; an armory; and the cloister of the church (as well as the Chapel itself) — as in Beerbohm Tree's production. A great Hall in Leonato's house; the crypt under the church (where the Monument to Hero was); and a quadrangle (instead of a courtyard) without Leonato's house, where were also shown the steps up to a cloister and church at the back and the "pent" and guard-house at the left — where huddle the city watch and where Conrad and Borachio are taken — thus combining several of the scenes in one large and elaborate set, as in Alexander's version. Hardly a new production but contains some one scene that is especial to that individual presentation; a statement that is also true of the present version, as placing the final scene on the terrace of Leonato's villa overlooking the Mediterranean is here an innovation.

The entire first act is taken up by the one scene in the "Courtyard before Leonato's House." This scene shows, to the left, (stage directions, it must be remembered, are always given for the right and left of the actor, as he stands facing the auditorium — and are therefore directly opposite from the right and left of the spectator) the entrance to the villa, through a projecting pavilion

of the house itself. Across the back of the stage runs a protecting wall some eight or nine feet high (painted on the "cut drop") separating the courtyard from the roadway that slowly climbs the hill from the city below. Through a gateway near the centre of this wall, a glimpse of the road parapet and, beyond, of the bay of Messina, is to be obtained (see frontispiece). The right side of the courtyard is taken up by the retaining wall of a terrace of the garden, which is here at a higher level, enabling those walking along the terrace above to look down to the courtyard and into the road and off on to the city and the bay with equal ease. This wall is bounded by an open balustrade overgrown with vines and broken near the centre by a Renaissance arched opening from just back of which start a flight of stone steps that, with a sharp turn "off-stage," supposedly lead to the terraced walk above. Beyond the wall and over its top appear the regularly planted cypresses of a garden alley. About the courtyard in terra cotta pots are placed formally clipped yew, laurel and orange trees; and overhead, thrown from the house out over the court and fastened to supports above and beyond on the terrace, is a broad awning of dark rich purple with a hanging band or border ornamented with gold and fastened with golden ropes. The porch of the house is raised a few steps, covered, and partially enclosed by square pilasters.

The color of this first scene largely depended on the contrast between the dark blue of the sky and green of the cypresses and vines, and the very light, almost white coloring of the yellowish-white marble walls of the house and courtyard. Even where slightly stained and weathered to transparent contrasting tints, the effect of the architecture, beneath the strongly concentrated sunlight of a southern mid-afternoon, was dazzlingly white. Beyond, the bright coloring of the Mediterranean Sea and the South Italian sky were both depicted on the "cyclorama drop" (or "cyc") that hung entirely through the evening at the extreme back, and down the sides of the stage, and showed the distant hills of the outlying islands and other shore of the bay, as well as the villages along the border of the Mediterranean. This drop was painted as a "transparency" (with semi-transparent clouds in the sky

painted on the back) so that, in the Garden scenes, certain effects of lighting simulating moonlight and sunrise could be obtained upon and through the hanging cloth.

The appearance of the returning soldiers near the opening of

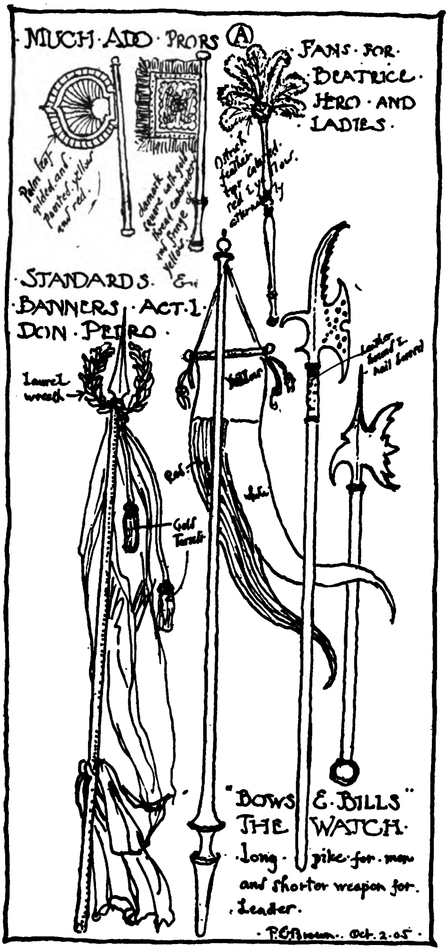


FIG. 1.

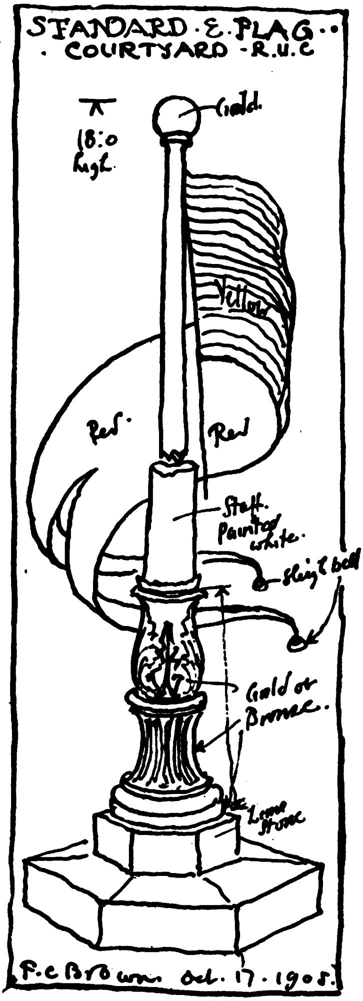


FIG 2.

the act enlivened the scene, bringing upon the stage various banners, pennants, etc., belonging either to their own army or supposed to have been captured from the enemy. (Figs. 1 and 2.) It would

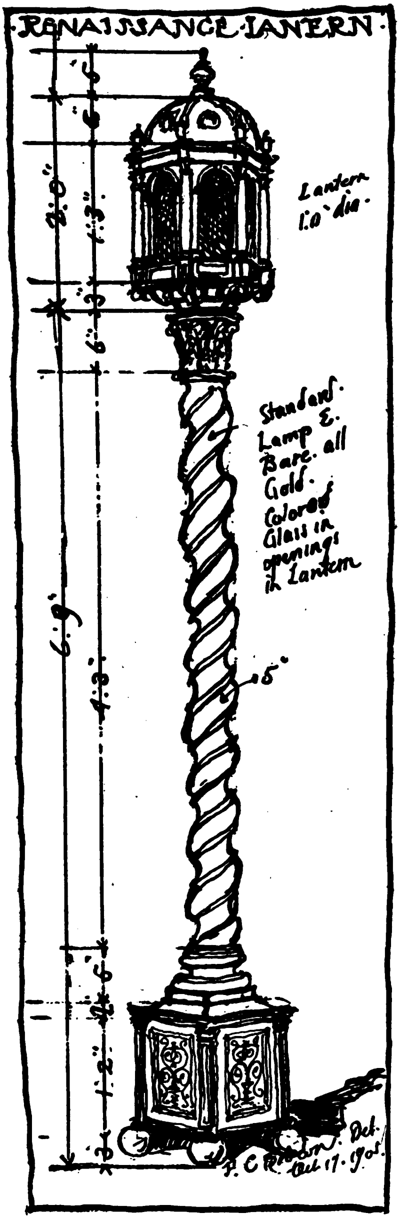


FIG. 3.

be quite within the bounds of probability that some portions of the house and porch itself would also have been especially decorated for the occasion offered by the arrival of these military and noble guests.

The second act opens at night, with the maskers and revellers dancing back and forth through the moonlit garden, or pausing briefly beneath the many-colored lanterns that hang in the arbor and at the gate, or are more formally disposed about the water pool. (Fig. 3.) Leonato's garden is perched upon the steep hillside behind the city and looks out at the back into the bay. Beyond a parapet wall and gateway, at the head of a staircase leading down to the harbor, appears the sea-view and the tops of the trees and cypresses growing upon the slopes that extend down to the valley below. On the left is an elaborate architectural fountain, water stained and lichen covered, with a semi-circular basin and larger garden pool below a central niche occupied by the figure of Neptune. This

stone curbed pool reflects on its surface the changing lights of the sky as well as of those torches set round about it. Above the fountain, at the left, appears a terrace with steps up to it; and

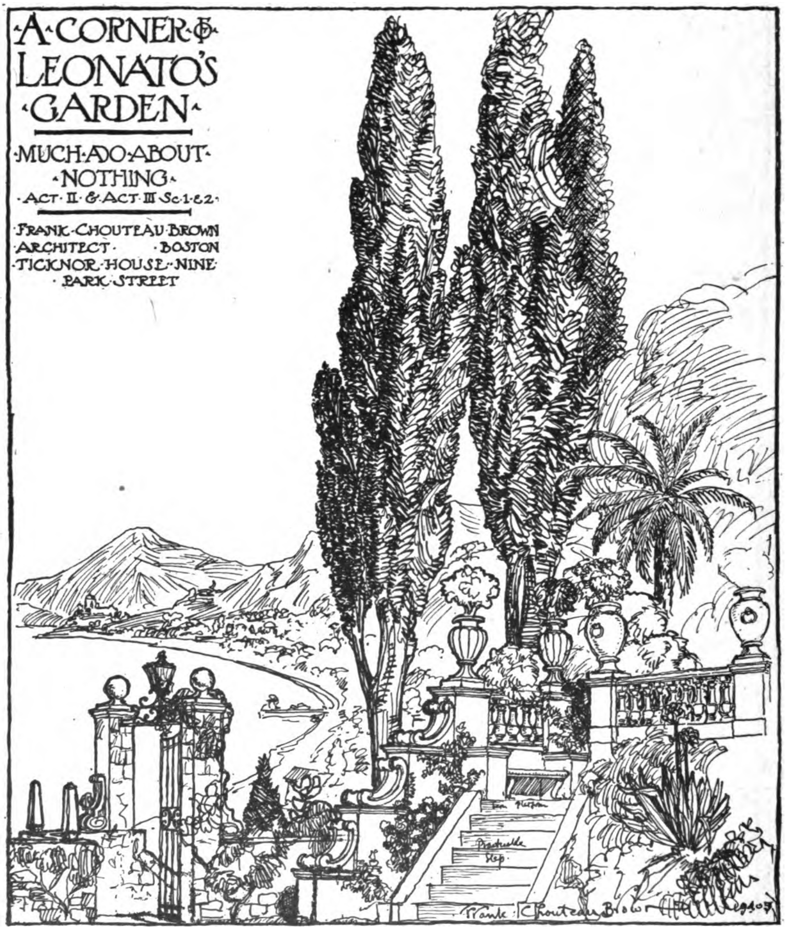


Fig. 4.

beyond the terrace, at a higher level, a glimpse of a portion of the less formal garden (Fig. 4).

On the right of the stage, nearest the audience, is the wall-enclosed gate connecting the garden with the roadway, and up stage of this gate is the latticed vine-covered summer house,

("Cruciform dog-house" it soon became in the slang of the theatre! "Dog-house," let me hasten to explain, being the regular term for any small, built-up house used upon the stage) which finishes the on-stage end of the "pleached alley" or arbor that runs off among the cypresses to the right. Directly behind, and on the same axis as the opening through the garden house, is seen a long vista, bordered by cypresses on the one side and the parapet wall along the edge of the sharp hill declivity on the other, with a terminal statue at the end,— indicating that that portion of Leonato's grounds here jut further out, nearer to and almost overhanging the margin of the sea.

The second act ends with the departure of maskers and guests, the extinguishing of the lanterns and closing of the gates by Leon-

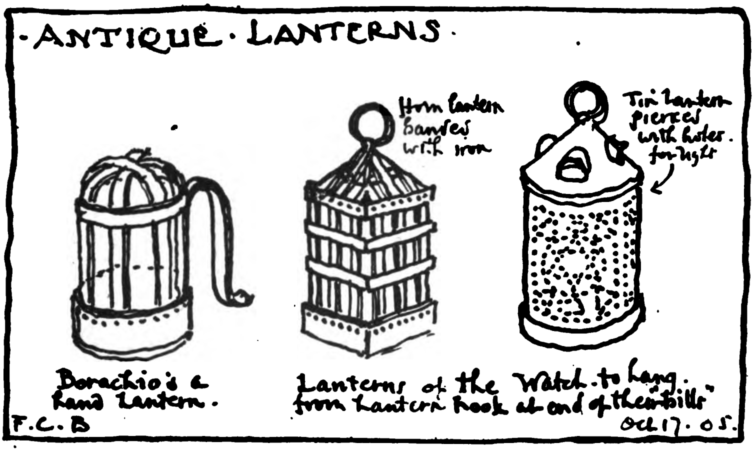


FIG. 5.

ato's servants; after which, in the night, Borachio searches for and finds Don John glooming in the garden and then, in black darkness (save for the gleam of the single candle in the lantern held by Borachio (Fig. 5), a light just sufficient to show their faces) is hatched the conspiracy that is afterwards put into execution. The conspirators are frightened away, but the curtain remains up with the stage in absolute darkness until the coming of the dawn pictures the beginning of the new day, and the following scene and act open with the appearance of Benedict from

outside the gate, returning with his falcon and attendant boy from an early morning hunt. During this scene is portrayed the ensnaring of Benedict; and during the second scene, in the afternoon, the parallel attack on Beatrice.

In color this setting still remained white and dazzling. The fountain, with the exception of the niche itself and the weather stained portions of the pool and basin which are damp and discolored, the gate posts and walls are all the same light tones, while the balustrades and steps are even more brilliantly yellowish-white. Only the older balustrade, supposedly bounding the verge of the declivity and painted on the cut drop at the rear, is warmer and browner in tone and more stained by lichen, moss and other vegetable growths.

At the end of this scene (the second scene in Act III) the garden set is finally "struck" or "taken away," and the night scene in a "Street in Messina" is shown. This is a "shallow" scene of short duration that comes down in front of the garden and is principally contained on two drops. At right and left are two plaster "house wings" to "mask in," with a "cut" "street drop" behind them, through the wide opening of which appears — painted on the "back drop" — a distance view along a street winding around the bay. The back drop also carries a glimpse of the waters of the harbor with a slightly transparent and cloudy sky that demarks, by the aid of a light from behind, and brings into partial silhouette the houses and the line of the horizon. The storm-murky twilight of the opening of the scene slowly vanishes as the night grows more and more unpleasant until it begins to drizzle, and the conspirators are finally driven to seek refuge under the "pent-house" over the very door of the redoubtable Dogberry himself. The lights in the windows of the houses painted on the back drop shine out more and more clearly as the night thickens, then gradually dim and go out one by one until, at the apprehending of Conrad and Borachio by the watch, the stage is left quite dark, and only the red and green side lamps and the high yellow riding lights of the vessels lying at anchor in the harbor are to be dimly seen through the thickness of the driving night.

The coloring in this scene is richer than any that has heretofore

been allowed. The houses are of brick, plaster or stone. When of plaster they are stained rich reds, snappy pinks and yellows, and yellow browns; when of stone they are as likely as not to be of a reddish tinged sandstone of considerable depth of color. Even the dust in the street is of a rather stronger yellowish and reddish hue.

The next scene brings us to the first set in Act IV, the interior of a church in Messina. This setting (of which a clear photograph was never obtained) showed Leonato's private Chapel within the church, where the wedding of Hero and Claudio is to take place and was, in design, a composite of several of the best known Sicilian churches. Much of the coloring and some of the details were suggested by the famous Capella Palàtina at Palermo, although the strictly architectural lines were more closely adapted from the less-known Chiesa della Martorana, in the same place. The scene was formed by a front "leg drop" with a large arched opening that hung directly behind the proscenium, through which appeared a second "cut drop" hung about eighteen or nineteen feet further "up stage." This second "cut drop" contained three arched openings closed, below, by an iron grill some eight feet in height. It is through these openings and this grill that the spectators looked out into the main body of the dimly seen church beyond, painted on the back drop and faintly lit from a dome above. The ceiling is broken by beams of gold, stencilled on blue, while the actual wooden ceiling sloping to an apex above them is darker and more sombre in tone. But little detail could be seen by the audience, but enough was suggested to grade the distance and suggest the elaborate ornamentation of the church beyond.

The interest was intentionally so concentrated on the modelling of the column shafts and on the lighting of the wall around the chapel altar in the right foreground, where the richest mosaics and most elaborate details all were. The chapel altar is sixteen feet wide, of yellowish marble in the main, but with panels of red and blue inlay and mosaics in white, gold and black designs. Upon the buttressed ends of the semi-circular niche which encloses the high and low altars are placed seven-branched candlesticks, all filled with candles. The left end of the front chapel is closed

in by a wall with a door opening which is painted, but not practicable. ("Practical" is the techincal expression, meaning — substantially — "usable." It indicates the distinction between a painted opening and one actually constructed so as to be used).

On the rise of the curtain the stage was in dim darkness, the seven

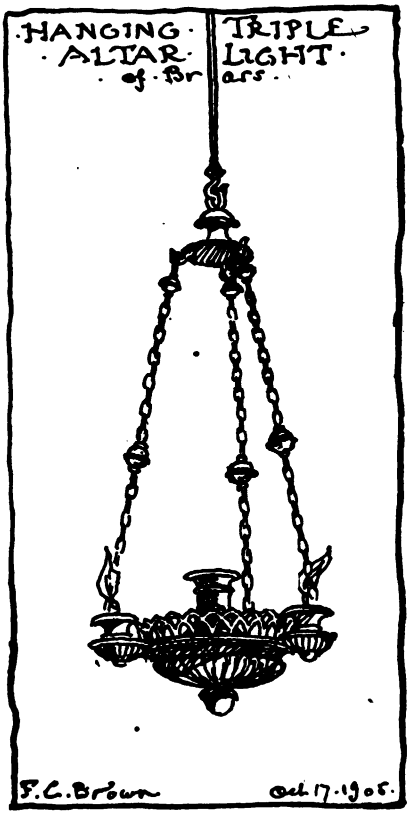


Fig. 6.

candles burning faintly on the grand altar at the end of the nave, and one light hanging in front of the altar in the Chapel (Fig. 6) down stage, right — being actually all the light to be seen upon the scene. On to the empty stage enter, from the sacristy, off stage right, attendants to light the altar candles while, at the same time,

the calciums in the fly gallery above and behind it, were gradually turned on until the space immediately in front of the altar was

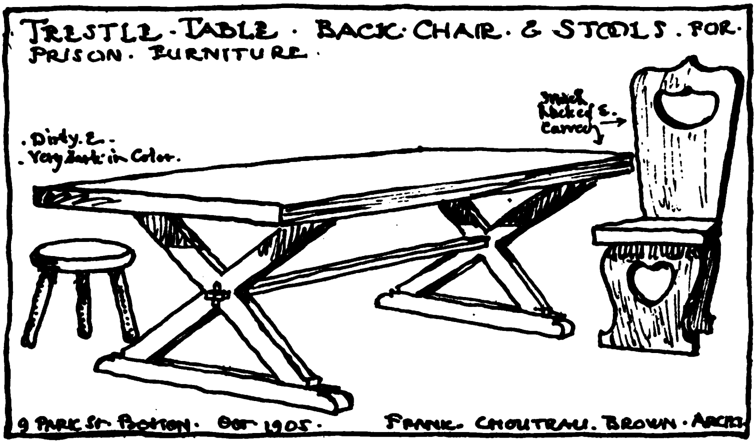


FIG. 7.

flooded with light that caught upon and picked out the single scarlet strip of carpet running from the steps of the altar down along the length of the chapel. The sacristan enters and opens the iron gates at the left end of the grill as the wedding procession

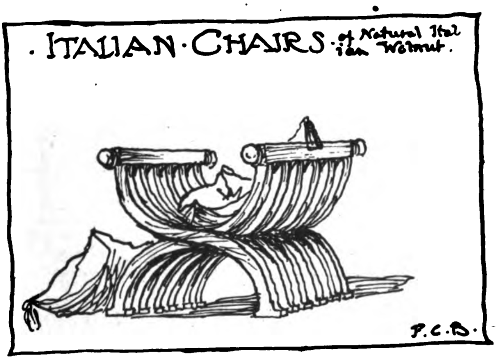


FIG. 8.

slowly approaches from the right on the "up stage" side of the screen and, passing acıoss behind the grill, enters through the gates in its left end and go up to the altar where the choir boys bob,

turn and pass out through the sacristy entrance just in front of the up stage netted drop; the whole providing an atmosphere and entrance appropriate to the pathetic scene that follows, before a word was spoken and even before the appearance of a single person on the stage.

In this church scene, the single act where the play first rises above the level of high comedy and for some moments is well contained within the bounds of tragedy, is found an illustration

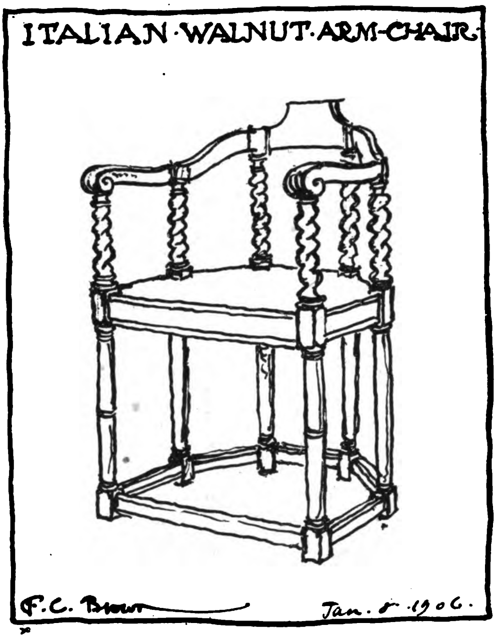


FIG. 9.

of the suggestive psychology of stage settings. The dim solemnity of the scene, the two or three lights burning in different locations about the stage, the distant music of the organ and choristers slowly approaching from without, along with the dignified progress of the wedding procession across the stage above the grillwork, their momentary disappearance and re-entrance through the gates at the left and their passing across to the altar at the right, gave the audience ample time to obtain the full effect of the picture, so

presaging — even for the least impressionable among them — the changed mood of the succeeding action. The lighting of the scene contained its own psychological value. In the blaze of light radiating in front of the altar stood the bride and her friends; from here Claudio handed her back to her father; and here Beatrice urged Benedict to "Kill Claudio!"; while Don John and his assistant conspirators kept their places in the opposite lower corner of the scene, the very gloomiest and darkest spot

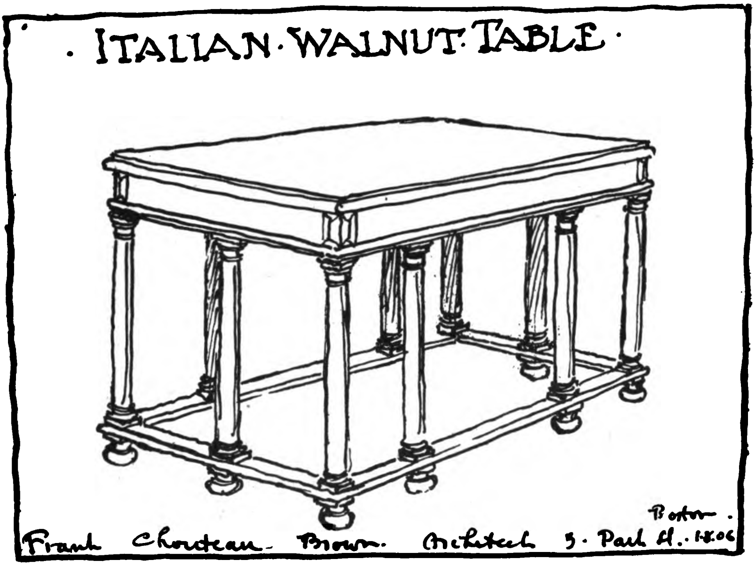


FIG. 10.

upon the stage, from which concealment they watched the enactment of the final moment of the conspiracy they had planned.

The last scene in this act is inside a prison, which represents the half of an octagonal dungeon, very simply composed of a cut drop hung well down front and a series of five tall flats set angularly behind it in the very centre of the stage. The painting of this set showed a grim, dimly lit and somewhat gruesome interior with stained and discolored plaster work, old masonry of different epochs, and even some old Roman brickwork. The color effect was lightened and its impressiveness increased by occasional stones

of rather uncanny whiteness built into the wall, over portions of which a few placards of various kinds had been carelessly pasted at one time or another. The ceiling represented a clumsy domed top painted upon the flats and requiring no border.

The last act opens with a first scene that is the same as in the first act, the Courtyard of Leonato's house; with the conditions of coloring, lighting, etc., all as before. This first scene was followed by a very shallow set consisting solely of one drop and a single foliage wing in front of it at right and left. By merely taking away the down stage wall at the right of the courtyard and the down stage wing of the house at the left, this drop could be lowered in front of the porch and platform, and the second scene could be started while the remainder of the first set was being finally taken away for that performance.

The second scene of the last Act is the exterior of the Tomb or "Monument" of Hero; an old eight-sided brick structure with a tiled roof, placed behind or beside the Chapel, and surrounded by gloomy cypresses and the partially ruined remains of a still older wall. At one side is the walled alley of a portion of a disused monastic garden whose extent is emphasized by the sentinel cypresses standing adown its length and glooming over its distant terminal feature. With this drop were used cypress wings, right and left, and a foliage border, pulled well up.

The last scene of all, the third in the Fifth Act, shows the inside of a Renaissance loggia looking out upon the terrace overlooking the bay of Messina and forming a part of Leonato's palace villa. Next to its requisites of quick setting and simplicity of arrangement, this scene was further devised especially to avoid the employment of the "sky border," than which no one of the scenic conventions of the theatre is more unconvincing, no subterfuge so baldly apparent. The cut drop—its upper portion painted into a ceiling arching out overhead — did away with the necessity of using any border in front; while this painted ceiling came down so low that but few in the audience could see the sky borders hanging well up out of the line of sight, behind. Simple as was this expedient, it was largely responsible for the unusually open airy and unobstructed effect that was, by this means, secured.

The drop hung about nine feet back of the proscenium arch and shows a double-columned triple-opening Palladian feature with an arch in the centre (Fig. 11) that looks out upon a paved and tessellated terrace. The columns of the loggia are of marble, and their capitals are twined with garlands drooping between the column shafts. The ceiling is a barrelled vault painted a Pom-

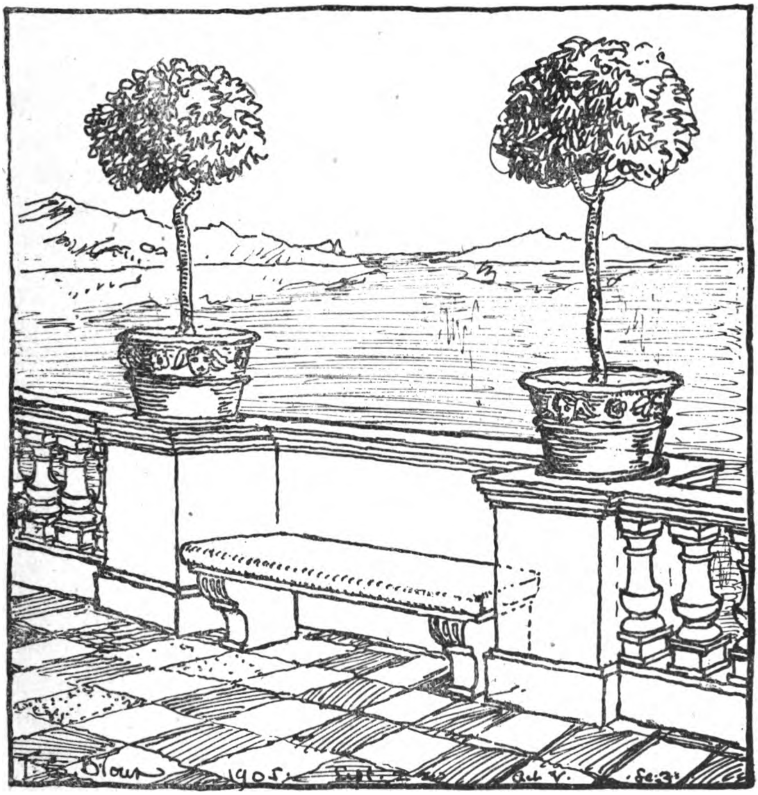


Fig. 12.

peian yellow with a stencilled ornament of the same style or period. The walls at either end of the loggia were of a dull Pompeian red above a dado of limestone, of which the architraves of the openings are also composed.

Looking out across the terrace there appeared a balustrade of white marble with a recessed seat in the centre (Fig. 12), potted

plants in red terra cotta garden pots, and clusters of bright flowers growing in green jade colored vases of large size at either end. Back of the cut drop, were low marble pavilions with arched openings to mask the ends of the "cyc" at each side. Between the pavilions and the balustrade low wide flights of several steps extend up stage, leading off right and left to higher levels, over which all the entrances are made throughout the scene. Here, for the first time, the cyclorama drop giving the distant view of the bay of Messina is fully disclosed. Wherever shown heretofore it has been partially masked by cut drops disclosing only the central portion; but now the entire distance view, from right to left, appearing above the balustrade and between the flanking pavilions of the loggia, may be fully seen. The lighting was brilliant and strong behind and back of the cut drop, while only the footlights were "full up" in front, so giving the effect of the full blaze of sunlight of a Sicilian afternoon upon the terrace and a certain sense of coolness within the Loggia itself, which appeared to increase and set back the terrace and distance of the scene.

(*To be completed in the June number.*)

ON SIMPLICITY OF METHOD IN ELEMENTARY DYNAMICS.

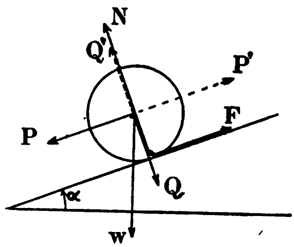
BY E. V. HUNTINGTON.

(*Continued from Vol. 5, page 184.*)

WE now give the solutions of a few representative problems, to illustrate the range of applicability of the working principles mentioned in the foregoing paragraphs.

Problem I. *A four-wheeled car rolls freely down an inclined plane. Assuming that each wheel carries one quarter of the load, and neglecting axle-friction, find* (a) *the acceleration of the car down the plane,* (b) *the pressure on the plane, and* (c) *the pressure between the truck and the wheels.*

NOTATION. Let w = weight of one wheel, r = radius, k = radius of gyration about the axle, W = the load carried by each wheel, a = inclination of the plane, F and N = components of the pressure between one wheel and the ground, resolved parallel to and normal to the plane, P and Q = components of the axle-pressure between each wheel and the corresponding quarter of the truck, v = velocity of car down the plane.



RESULTS. The required acceleration is

$$\frac{dv}{dt} = (1 - C)\ g \sin a,$$

and the required reactions are

$$F = C\ (W + w) \sin a, \qquad N = (W + w) \cos a,$$
$$P = C\ W \sin a, \qquad Q = W \cos a,$$

where C is an abbreviation for a proper fraction determined by

$$\left(1 + \frac{w}{W + w}\frac{k^2}{r^2}\right) C = \frac{w}{W + w}\frac{k^2}{r^2}$$

and depending merely on the weight and dimensions of the car.

PROOF OF RESULTS. First, consider the motion of the wheel alone, the wheel being a separate rigid body free to move under the forces F, N, P, Q, and w. Applying the principle of the centre of gravity, taking components along and normal to the plane, we have

$$w \sin a + P - F = \frac{w}{g} \frac{dv}{dt} \tag{1}$$

and

$$w \cos a + Q - N = 0. \tag{2}$$

Applying the principle of rotation about the hub, and noticing that $\omega = v/r$ (since there is no slipping on the plane), we have

$$r F = \frac{w}{g} k^2 \frac{1}{r} \frac{dv}{dt}. \tag{3}$$

These three equations contain all the information that can be derived from the motion of the wheel as a separate body.

Secondly, consider the motion of the truck alone, this being a separate rigid body free to move under the forces P', Q', and W (where P' and Q' are equal and opposite to P and Q). In this case there is clearly no rotation; but by applying the principle of the centre of gravity, we have

$$W \sin a - P = \frac{W}{g} \frac{dv}{dt} \tag{4}$$

and

$$W \cos a - Q = 0. \tag{5}$$

These five equations (1) — (5) are then sufficient to determine the five unknown quantities dv/dt, F, N, P, and Q, the solutions being given above.

Note. If the internal reactions P and Q are not required, a shorter method of finding dv/dt, F, and N may be obtained by *applying the principle of the centre of gravity to the whole system* comprising wheel and truck together; this gives, for components along and normal to the plane,

$$(W + w) \sin a - F = \frac{W + w}{g} \frac{dv}{dt}, \tag{6}$$

and

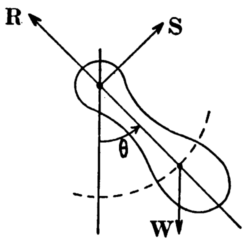
$$(W + w) \cos a - N = 0. \tag{7}$$

Equations (6) and (3) are sufficient to determine dv/dt and F, and equation (7) determines N.

Problem 2. The Pendulum.

A rigid body is free to rotate about a fixed horizontal axis, under the force of gravity. Find the angular velocity and the reactions on the axis, for any position of the body; and find the length of the "equivalent simple pendulum."

Notation. Let W = weight, k = radius of gyration about the fixed axis, a = distance from the axis to the centre of gravity, θ = the angle which the central line of the body makes with the vertical at any time t, and R, S = the components of the hinge-reaction along and perpendicular to the central line of the body. Let the time t be measured from the lowest point of the swing, so that $\theta = 0$ when $t = 0$; and let ω_0 be the angular velocity at that point.



Results. The angular velocity ω for any position θ is given by

$$\omega^2 = \omega_0^2 - 2\,g\,\frac{a}{k^2}\,(1 - \cos\theta),$$

where ω_0 is the angular velocity at the lowest point ($\theta = 0$); or, if the body starts from rest at $\theta = \theta_1$, we have $\cos\theta_1 = 1 - \frac{k^2}{2\,ga}\,\omega_0^2$, and hence

$$\omega^2 = 2\,g\,\frac{a}{k^2}\,(\cos\theta - \cos\theta_1).$$

The reactions of the axis are given by

$$S = \frac{k^2 - a^2}{k^2}\,W\sin\theta,$$

and

$$R = \frac{k^2 + 2a^2}{k^2}\,W\cos\theta + Wa\left(\frac{\omega_0^2}{g} - 2\,\frac{a}{k^2}\right)$$

$$= W\cos\theta + \frac{2Wa^2}{k^2}\,(\cos\theta - \cos\theta_1).$$

It will be noticed that if $\omega_0^2 > \frac{4\,ga}{k^2}$, the body will perform complete revolutions about the axis, θ_1 being imaginary.

If the weight is concentrated at a point distant l from the axis, then $a = k = l$, and the results just obtained become

$$\omega^2 = \frac{2\,g}{l}(\cos\,\theta - \cos\,\theta_1), \quad S = 0, \quad R = W(3\,\cos\,\theta - 2\,\cos\,\theta_1).$$

Comparing these results with those for the general case, we see that *a simple pendulum of length l will move with the same velocity as the given pendulum, provided*

$$l = \frac{k^2}{a};$$

but the reactions on the axis will not be the same in the two cases.

By the aid of these results, the radius of gyration of a given solid about any axis can be found experimentally as follows: suspend the body on a knife-edge along the given axis, and adjust the length of a simple pendulum until it swings isochronously with the given body; then measure a and l, and compute k^2 from the relation $l = k^2/a$. (The radius of gyration k_0 about a parallel axis through the centre of gravity will be given by $k_0^2 = k^2 - a^2$.)

Proof of Results. The body is free to move under the forces R and S, acting at the upper end, and the force of gravity, W, acting at the centre of gravity. The centre of gravity moves in a circular path with a variable angular velocity ω, and therefore has a normal acceleration $\omega^2\,a$ and a tangential acceleration $(d\omega/dt)\,a$.

Hence, applying the principle of rotation, we have

$$-Wa\,\sin\,\theta = \frac{W}{g}\,k^2\,\frac{d\omega}{dt}; \tag{1}$$

and taking the normal and tangential components of the motion of the center of gravity we have

$$R - W\,\cos\,\theta = \frac{W}{g}\,\omega^2\,a \tag{2}$$

and

$$S - W\,\sin\,\theta = \frac{W}{g}\,\frac{d\omega}{dt}\,a. \tag{3}$$

These three equations, with the initial conditions $\theta = 0, \omega = \omega_0$ when $t = 0$, completely determine the motion.

Multiplying (1) by $d\theta$, and noting that $dv/dt = \omega$, we have

$$-ga\,\sin\,\theta\,d\theta = k^2\omega\,dw;$$

whence, after determining the constant of integration, we have

$$\omega^2 = \omega_0^2 - 2g \frac{a}{k^2} (1 - \cos \theta).$$

To find R, substitute in (2) the value of ω^2 just obtained; to find S, substitute in (3) the value of $d\omega/dt$ obtained from (1).

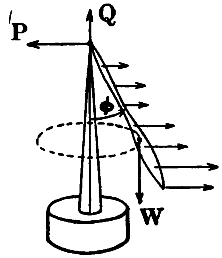
Note. If the amplitude is small, $\sin \theta$ is nearly equal to θ,* and equation (1) may be written $-g\theta = l \frac{dw}{dt}$ (putting $l = k^2/a$). Integrating as before, we obtain

$$\theta = \theta_1 \sin \left(t\sqrt{\frac{g}{l}}\right).$$

Hence the periodic time for a *small* vibration is approximately $2\pi \sqrt{\frac{l}{g}}$. The periodic time is the time required for a complete vibration over and back ("swing-swang"); a "seconds pendulum" or a pendulum that "beats seconds," crosses the vertical once every second, and has therefore a periodic time of two seconds.

Problem 3. The Governor or Conical Pendulum.

A rod of variable density is hinged at one end to a vertical shaft. When the shaft revolves uniformly at N revolutions per minute, the rod hangs at an angle ϕ from the vertical. Find the relation between N and ϕ; and find the reactions at the point of support.



NOTATION: Let W = weight of the rod, k = radius of gyration about the upper end, and a = distance from the upper end to the centre of gravity; and let P and Q be the horizontal and vertical components of the reaction of the hinge.

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* Notice that the approximation $\cos \theta = 1$ is not as accurate as $\sin \theta = \theta$, and is in fact not sufficiently accurate for the present purpose.

RESULTS: The required relation between N and ψ is given by

$$\frac{k^2}{a}\cos\psi = \frac{900\,g}{\pi^2 N^2};$$

the required reactions are then

$$P = \frac{\pi^2 N^2}{900}\frac{W}{g}\,a\sin\psi;\quad Q = W.$$

If the weight of the rod is concentrated at its lower end, $k = a = l$, and hence $k^2/a = l$. In this case $(k^2/a)\cos\psi = l\cos\psi$ is called the *height of the governor*, being the altitude of the cone described by the rod; the height of the governor depends merely on the speed of revolution and not on the length of the rod. It will be noticed that N^2 must be greater than $\frac{900\,g}{\pi^2}\frac{a}{k^2}$ before the rod will leave the vertical.

PROOF OF RESULTS. Each element of the rod, at distance x from the upper end, and of weight dw, is revolving uniformly in a horizontal circle of radius $x\sin\psi$; the total acceleration of the element is therefore directed toward the axis of revolution, and is equal to $\frac{\pi^2 N^2}{900}x\sin\psi$ (by § 1, *d*). Hence, *if we apply to each element a force which would produce this same acceleration in the opposite direction,* the whole rod will be reduced to rest. The external forces acting in the rod will then be the following:

the forces of gravity, dw, acting on each particle, downward;

the forces P and Q, acting at the upper end of the rod;

the additional forces $\frac{dw}{g}\frac{\pi^2 N^2}{900}x\sin\psi$, acting on each particle in a horizontal direction away from the axis.

Now, by D'Alembert's principle, these external forces will be in equilibrium. Hence, taking moments about the upper end,

$$\int_{x=0}^{x=l}\left(\frac{dw}{g}\frac{\pi^2 N^2}{900}x\sin\psi.\ x\cos\psi\right) = \int_{x=0}^{x=l}(dw\sin\psi),$$

or, since N and ψ are constant throughout the integration,

$$\frac{\pi^2 N^2}{900\,g}\cos\psi\int_{-}^{-}x^2\,dw = \int_{-}^{-}x\,dw. \tag{1}$$

Again, taking horizontal and vertical components,

$$P = \frac{\pi^2 N^2}{900\, g} \sin\psi \int_{x=0}^{x=l} x\, dw \tag{2}$$

and

$$Q = W. \tag{3}$$

These three equations lead at once to the results given above, since

$$\int\limits_{-}^{-} x\, dw = W a \qquad \text{and} \qquad \int\limits_{-}^{-} x^2 dw = W k^2,$$

by the definitions of centre of gravity and radius of gyration (§ 4, 5).

Problem 4. Impact. *A body W_1 moving along a straight line with velocity v_1 overtakes a body W_2 moving along the same line with velocity v_2. Find the velocities v_1' and v_2' after impact, and the loss of energy due to the collision.*

Assume that

$$\frac{v_2' - v_1'}{v_1 - v_2} = \frac{\text{relative veloc. after impact}}{\text{relative veloc. before impact}} = e,$$

where e is an empirical constant called the *coefficient of restitution* and depending merely on the nature of the materials.

Results.

$$v_1' = v_1 - \frac{W_2}{W_1 + W_2}(v_1 - v_2)(1 + e),$$

$$v_2' = v_2 + \frac{W_1}{W_1 + W_2}(v_1 - v_2)(1 + e),$$

$$(\text{En}) - (\text{En})' = \frac{1}{2g}\,\frac{W_1 W_2}{W_1 + W_2}(v_1 - v_2)^2(1 - e^2).$$

In the special case where $e = 0$, the two bodies proceed after impact with a common velocity $V' = v_1' = v_2'$, where

$$V' = \frac{W_1 v_1 + W_2 v_2}{W_1 + W_2}.$$

Proof of Results. Let F be the (variable) force which acts between the bodies during the interval of contact.* Then for the motion of the centre of gravity of the first body at any time within this interval we have

* Note that the bodies cannot be regarded as rigid bodies during the interval of contact.

$$F = -\frac{W_1}{g}\frac{dv}{dt},$$

whence

$$\int_0^t F dt = -\frac{W_1}{g}(v_1' - v_1). \tag{1}$$

Similarly, for the second body,

$$\int_0^t F dt = +\frac{W_2}{g}(v_2' - v_2). \tag{2}$$

Eliminating the integral of the unknown force from (1) and (2), we have

$$W_1 v_1' + W_2 v_2' = W_1 v_1 + W_2 v_2; \tag{3}$$

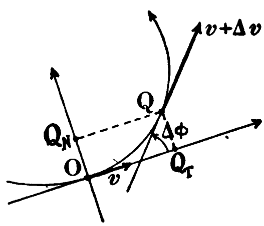
that is, the total momentum of the system is the same before and after impact. Solving this equation with $(v_1 - v_2)\, e = v_2' - v_1'$ we obtain v_1' and v_2' as above.

The loss of energy is the difference between the total energy of the system before and after collision, that is,

$$(\mathrm{En}) - (\mathrm{En})' = \frac{W_1}{g}\frac{1}{2}v_1^2 + \frac{W_2}{g}\frac{1}{2}v_2^2 - \left(\frac{W_1}{g}\frac{1}{2}v_1'^2 + \frac{W_2}{g}\frac{1}{2}v_2'^2\right),$$

which reduces to the value given above.

In conclusion, we add the demonstrations of two of the theorems stated in the first part of the article (§ 1, b).



In these proofs we assume that the expressions for the components of the velocities (which present in difficulty) have been already obtained, and that

$$\lim \frac{\sin \Delta\theta}{\Delta\theta} = 1 \qquad \text{and} \qquad \lim \frac{1 - \cos \Delta\theta}{\Delta\theta} = 0.$$

Proof of the formulae for components of acceleration along tangent and normal (§ 1, b).

Consider the tangent and normal at a fixed point O of the curve, and let P_T and P_N be the projections of the particle P on these fixed lines. Suppose that at the time t the particle P is at the point O and has a path-velocity v, while at the time $t + \Delta t$ it is at the point Q and has a path velocity $v + \Delta v$. Then during the interval Δt the point P_T moves from O to Q_T, and its velocity changes from v to $(v + \Delta v) \cos \Delta \phi$; and the point P_N moves from O to Q_N, and its velocity changes from O to $(v + \Delta v) \sin \Delta \phi$.

Hence the acceleration of P_T at the point O is

$$A_T = \lim \frac{(v+\Delta v) \cos \Delta \phi - v}{\Delta t}$$

$$= \lim \left[\frac{\Delta v}{\Delta t} \cos \Delta \phi - v \frac{1 - \cos \Delta \phi}{\Delta \phi} \frac{\Delta \phi}{\Delta t}\right]$$

$$= \frac{dv}{dt},$$

and the acceleration of P_N at the same point is

$$A_N = \lim \frac{(v + \Delta v) \sin \Delta \phi - 0}{\Delta t}$$

$$= \lim \left[v \frac{\sin \Delta \phi}{\Delta \phi} \frac{\Delta \phi}{\Delta t} + \frac{\Delta v}{\Delta t} \sin \Delta \phi\right]$$

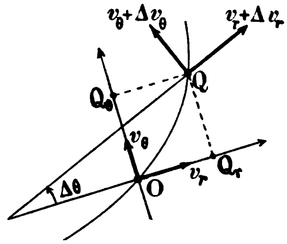
$$= v \frac{d\phi}{dt} = \frac{ds}{dt} \frac{d\phi}{dt}.$$

Hence $$A_N = \left(\frac{ds}{dt}\right)^2 \frac{1}{R}, \text{ where } \frac{1}{R} = \frac{d\phi}{ds}$$

Proof of the formulae for components of the acceleration along and perpendicular to the radius vector (§1, b).

Consider the radius vector and the perpendicular to the radius vector at a fixed point O of the curve, and let P_r and $P\theta$ be the projections of the particle P an these fixed lines. Suppose that at the time t the particle P is at the point O and has velocities v_r and v_θ along and perpendicular to the radius vector at that point, while at the time $t + \Delta t$ it is at the point Q and has velocities $v_r + \Delta v_r$ and $v_\theta + \Delta v_\theta$. Then during the interval Δt the point P_r moves from O to Q_r and its velocity changes from v_r to

$(v_r + \Delta v_r) \cos \Delta\theta - (v_r + \Delta v_\theta) \sin \Delta\theta$; and the point P_θ moves from O to Q_θ and its velocity changes from v_θ to $(v_r + \Delta v_r) \sin \Delta\theta + (v_\theta + \Delta v_\theta) \cos \Delta\theta$.



Hence the acceleration of P_r at the point O is

$$A_r = \lim \frac{(v_r + \Delta v_r) \cos \Delta\theta - (v_\theta + \Delta v_\theta) \sin \Delta\theta - v_r}{\Delta t}$$

$$= \lim \left[\frac{\Delta v_r}{\Delta t} \cos \Delta\theta - (v_\theta + \Delta v_\theta) \frac{\sin \Delta\theta}{\Delta\theta} \frac{\Delta\theta}{\Delta t} - v_r \left(\frac{1 - \cos \Delta\theta}{\Delta\theta}\right) \frac{\Delta\theta}{\Delta t}\right]$$

$$= \frac{dv_r}{dt} - v_\theta \frac{d\theta}{dt};$$

and the acceleration of P_θ at the same point is

$$A_\theta = \lim \frac{(v_r + \Delta v_r) \sin \Delta\theta + (v_\theta + \Delta v_\theta) \cos \Delta\theta - v_\theta}{\Delta t}$$

$$= \lim \left[v_r \frac{\sin \Delta\theta}{\Delta\theta} \frac{\Delta\theta}{\Delta t} + \frac{\Delta v_\theta}{\Delta t} \cos \Delta\theta + \frac{\Delta v_r}{\Delta t} \sin \Delta\theta - v_\theta \frac{1 - \cos \Delta\theta}{\Delta\theta} \frac{\Delta\theta}{\Delta t}\right]$$

$$= v_r \frac{d\theta}{dt} + \frac{dv_\theta}{dt}.$$

Substituting the values $v_r = dr/dt$ and $v_\theta = r d\theta/dt$, we have

$$A_r = \frac{d^2 r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2 \text{ and } A_\theta = r\frac{d^2\theta}{dt^2} + 2\frac{d\theta}{dt}\frac{dr}{dt}.$$

HARVARD ENGINEERING JOURNAL.

A QUARTERLY

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY.

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.

Subscription Rates.

Per year, in advance	$1.00
Single copies	.35

Address all communications :—

HARVARD ENGINEERING JOURNAL,
Room 218, Pierce Hall,
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.

Editorial.

Through an unfortunate oversight the resolutions passed by the Department of Architecture, on the death of Mr. W. D. Swan, were omitted from the notice printed in the last issue of the Journal. They appear below.

January 4, 1907.

We, the members of the Department of Architecture, wish to express to the family of our dear friend, Walter Dana Swan, our deep sympathy with their great loss, which is also ours. What his manly, courageous, and refined nature has been to his colleagues and to his students cannot be told. As a man he was so gentle, so sympathetic; as a teacher so intelligent, so kind, so helpful. His loss is irreparable, and he will not be forgotten.

It is our wish to put on record this expression of our affection for him, and of our sense of the great value of the services and the companionship that is now lost to us.

(*Signed*) H. Langford Warren,
Denman W. Ross,
Frederick Law Olmsted Jr.,
William L. Mowll,
James Sturgis Pray,
Henry V. Hubbard,
Harold V. Skene.

The annual dinner of the Harvard Engineering Society was held at the Union, March 2, 1907. Nearly 150 men, graduates and undergraduates, attended, making the affair a very pronounced success. Professor I. N. Hollis acted as toast-master and introduced the following speakers: G. S. Rice, '70, Chief Engineer, Rapid Transit R. R. Commission, New York; J. R. Worcester, Consulting Engineer, Boston; Franklin Remington, '87, President Foundation Co., New York; F. L. Gilman, '95, Western Electric Co., New York; J. A. Moyer, '99, General Electric Co., Lynn; H. M. Hale, '04, Rapid Transit R. R. Commission, New York; and Messrs. H. P. Forté, H. L. Lincoln, H. M. Turner, and W. C. Brinton, all of 1907, representing the Engineering Society and the three branch clubs — the Electrical, Civil and Mechanical.

The speeches were all very interesting, being in large part reminiscences of the experiences which our graduates have had since leaving college. Mr. Rice spoke of the opportunities for

young engineers on the subway work in New York, and urged the men to begin there after graduation. Mr. Worcester spoke just as warmly about the prospects in Boston, remarking that Boston was spending much more money than people realized on engineering construction. The other speakers gave us some idea of the kinds of work in which they were engaged.

The general subject for discussion, however, was the widening the influence of the Harvard Engineering Society and all the speakers expressed their opinions on the advisability of taking such a step. It seemed to be the unanimous idea that an organization which would keep the graduates in closer touch with each other, would promote a feeling of comradeship among Harvard men interested in Engineering after they had left college, would be excellent in every respect.

The outcome of the discussion was the appointment of a committee to carefully consider the question and report not later than Commencement, 1907. This committee is made up as follows: Professor L. J. Johnson, chairman, Messrs. G. S. Rice, F. W. Dean, J. F. Vaughan, F. L. Gilman, H. M. Hale, H. P. Forté.

The Harvard Engineering Society.

At two recent dinners a large number of graduates of Harvard interested in engineering have been brought together for the discussion of better organization. There is at present an undergraduate association, which was established in 1893 as the Harvard Engineering Society. It has been carried on for fourteen years wholly under the direction of student officers elected by the students; and while it has been extremely useful in stimulating interest in lectures from outside men and in training the students to manage their organization, it has not reached the great body of graduates, many of whom were members of the Society while in college. They left with the idea that, having separated themselves from the University, they were no longer specially interested in the membership of the Society. In order to do away with this notion and to promote a better understanding among all graduates of the University who have studied engineering at Cambridge,

or who have gone into engineering work after having graduated from the Academic Department of the University, it was thought well to have several meetings this spring, and the dinners above mentioned were found to be the most natural and effective method of getting the men together.

The first of these dinners was held at the Broadway Central Hotel in New York on February 16. It was attended by eighty-five men, most of whom had degrees in engineering from the University. Mr. George S. Rice presided, and his enthusiastic reception gave the dinner a most agreeable and informal tone. The meeting was highly successful in bringing out the points of mutual interest among the various Harvard men employed in engineering capacities near New York. The second dinner was the annual dinner of the Harvard Engineering Society, and was held at the Harvard Union on Saturday, March 2. It was equally a very great success, having brought together one hundred and forty-four men, including students, and graduates returned to Cambridge for the purpose of attending the dinner. It was presided over by Professor Hollis, and was succeeded by a discussion of the advisability of more thorough organization. The importance of the dinner to the members of the Harvard Engineering Society and to Harvard University is therefore not to be gauged by its mere social success. A resolution, introduced by Mr. H. M. Hale, '04, was unanimously adopted to appoint a committee, to report not later than Commencement, 1907, on means for effecting a closer affiliation among Harvard men interested in engineering.

The committee is to consist of Professor L. J. Johnson, '88, as chairman; Messrs. G. S. Rice, '70; F. W. Dean, '75; J. F. Vaughan, '95; F. L. Gilman, '95; B. M. Hale, '04; and H. P. Forté, '07. It will have authority to add two more to its membership, if found necessary in connection with its deliberations; and it will be expected to consider the whole subject of the relation of engineering in the University to the graduates occupied in engineering outside of the University. The membership of the Committee will be found to represent graduates both from the College and the Scientific School, inasmuch as both these classes

of men are equally interested in the engineering instruction at the University. It is hardly yet realized by the graduates, especially those from the Academic Department, that Engineering forms a very large part of the undergraduate instruction at the University. The courses, excepting those in shop work, may all be counted towards the degree of A. B., and a student entering the College may in three or four years obtain a very fair education in engineering while studying for the degree in Arts. The importance therefore of bringing together all Harvard men interested in engineering without regard to the Department or Division under which they studied while in the University, is very great; so that the discussion of the subject among Harvard men at these two dinners was timely.

Many advantages will follow from effective organization, one of the chief being a means of promoting the progress of engineering at the University by seeing that all men who graduate in that subject are provided with positions upon leaving the University. During the past ten years there has been so great a wave of prosperity throughout the country that no graduate has lacked employment within a comparatively short time after leaving the University. There has also been a great amount of municipal and state work going on in New York and in other places, offering opportunities to young graduates, especially those in civil engineering. Furthermore, the great companies for manufacturing machinery, such as the General Electric, the Westinghouse, and the Allis-Chalmers, have established apprentice systems, with the avowed purpose of giving employment to a large number of college men. This has assisted materially in making openings for Harvard men. The employment of engineers is, however, so dependent upon the commercial prosperity of the country that any fluctuation may easily throw large numbers of men out of employment. Besides this, the increasing number of graduates from the western schools is likely to render competition in getting employment very keen. There seems, therefore, to be good reason for organization in the direction of looking after Harvard men, even though at present they make their way from the start. There is no reason why, when once they get started in the profession of engineering, Harvard graduates should not do as well as graduates from other schools,

or even better, and the Division of Engineering has entire faith in its men. At the same time, the friendly help of another is always stimulating to any professional man; hence the social side of a better organization must not be neglected.

From another standpoint, the Harvard Engineering Society among the graduates can be of use in teaching engineering at Harvard, by suggesting improvement and by assisting to bring the needs of the Department to the attention of those who would be likely to contribute to its development.

One of the means suggested towards better organization was to establish in New York City a Harvard Engineering Society for graduates of the University interested in engineering within easy reach of New York. It was found at the first dinner, above mentioned, that there were over a hundred of these men, who could be mutually helpful to one another in many ways. Similar societies, as time goes on, could be established in other large cities, for the purpose of making the graduates of different years known to one another, and of establishing a community of interest among them.

The students' society at Cambridge would continue, its chief functions being the procurement of lectures, the discussion of engineering subjects, and the publishing of the Harvard Engineering Journal. This Journal has been in existence for several years and has gradually been placed in a position where it can pay for itself financially. Support is, however, needed among the graduates in the way of subscriptions to the numbers and suggestions as to the best method of making the publication acceptable to those who receive it. It is proposed, in future, to make much more of a point of publishing the addresses and items about graduates. To that end, this number contains a list of men who have been in the Scientific School and who have either graduated in engineering or have taken a large number of courses in engineering. This list will be followed later on by other lists, as they can be made up, of men who have graduated from the College and have subsequently gone into engineering. It is hoped that the graduates of the University will assist in making this list complete by sending in the names of those who are now in engineering, with their addresses;

also by completing the list published in this issue, with the addresses of those we have not yet heard from. Moreover, graduates and advanced students may naturally desire to publish in the Journal the results of their own technical achievements and experiences, in the form of papers. It is hoped that this periodical can thus be made valuable to engineers generally.

Another respect in which closer association and organization may become valuable will be in making the teaching of engineering at the University better known to former graduates, who were in Cambridge at the time when the subject was in eclipse. The past fifteen years have seen a great change both in standards and in the equipment for teaching, so that graduates in engineering are now fully as well educated as men coming from other technical departments or schools. This should be known by all Harvard men, many of whom are interested, as directors and owners, in great manufacturing companies.

It is planned to have a third meeting during Commencement week, when many of the graduates would naturally return to Cambridge; and if found possible, a definite project will be set before all Harvard men engaged in engineering work, looking towards local organization and regular meetings.

Prof. I. N. Hollis.

Harvard Mechanical Club.

Since the last issue of the Journal the Club has met but once. At this meeting, held Feb. 20th, Capt. Charles H. Manning, consulting Engineer for the Amoskeag Mills at Manchester, N. H., was the speaker. Capt. Manning gave a very interesting talk, telling of training given a young engineer about the time of the Civil war. Many experiences connected with early engineering projects were told in a very entertaining way. Special mention was made of the large flywheel at Manchester some time ago.

The next meeting of the Club is on Wednesday, March 20, when Professor S. A. Reeve of the Worcester Polytechnic Institute will speak on his own experiences with refrigerating machinery.

Civil Engineering Club.

The February meeting of the Civil Engineering Club was of a social character. The speaker for the March meeting is to be Mr. John Ware, formerly with the Pennsylvania Railroad, but now with the Boston Elevated. He will speak on the "Organization of a Railroad Operating Department and the Relation of an Engineer to it." This is a subject that is not usually considered in connection with the engineer and the talk promises to be most interesting.

Electrical Club.

At the February meeting of the Electrical Club, Dr. Louis Bell gave a talk about the Physiological Effects on the Eye, of Illuminants," particularly in respect to their colors, discussing the relation of high efficiency with the complete spectrum.

At the business meeting, before the talk, W. C. Bennett, '08, was elected treasurer of the club, in place of G. A. McKay, '08, resigned.

A list of Harvard men graduated since 1893, and at present engaged in engineering work, is printed for the information of all readers of the Journal. The majority of these men have graduated with the Engineering degree, but others have the General Science degree. In many cases the Division of Engineering has not been able to obtain correct addresses, and the names are therefore placed in two lists. Any Harvard man who knows the whereabouts of graduates whose addresses are not given on these lists will confer a favor by sending a postal card with the addresses to Professor I. N. Hollis.

A list of College men who have gone into engineering since leaving Harvard will be published in a future issue, and in order to make the list as complete as possible, all graduates are requested to send the names of such men to Professor Hollis.

The list of Scientific School men in engineering will also be completed in a future issue by adding those who graduated before 1894.

Graduates who have sent in Addresses, February-March, 1907.

[Residence is in Massachusetts, unless otherwise stated.]

ADAMS, K. E., care of Stokes & Smith Co., 1011 Diamond St., Philadelphia, Pa.
ALLEN, H. V. D., Empire Bldg., Atlanta, Ga.
ANDREWS, H. W., 3 Hammond St., Cambridge.
ANDRUS, L. A., 1131 Massachusetts Ave., Cambridge.
ARMISTEAD, D. W. A., Westinghouse Machine Co., E. Pittsburg, Pa.
AYER, E. M., care of Barber-Coleman Co., Rockford, Ill.
BALDWIN, J. R., Bellows Falls Canal Co., Bellows Falls, Vt.
BANCROFT, A. W., 89 Maple St., Gardner.
BARKLAGE, W. F., P. O. Box 45, Riverside, Ill.
BARNES, D. C., 17 Lancaster St., Cambridge.
BATCHELDER, W. O., 14 Union St., Schenectady, N. Y.
BECKER, S. K., Lackawanna Club, West Seneca, N. Y.
BLAKE, E. M., 8 Beacon St., Boston.
BLYE, J. N., 362 Fifth Ave., New York, N. Y.
BUCKE, J. H., 10 Andrews St., Cambridge.
CARROLL, H. H., 23 Maple St., Arlington.
CHAMBERLIN, J. B., 20 Congress St., Boston.
CHENEY, H. N., 212 Savin Hill Ave., Dorchester.
CHICKERING, Tileston, 244 S. Highland Ave., Pittsburg, Pa.
CLARK, G. E., Windsor Locks, Conn.
CLARK, W. E., Clark & Mills Co., 543 Boylston St., Boston.
COFFIN, F. P., 223 Union St., Schenectady, N. Y.
COFFIN, L. R., 1136 Hancock St., Quincy.
CRAWFORD, G. C., 321 W. 22nd St., New York, N. Y.
CROSSE, S. R., 25 Ware St., Cambridge.
CUNNINGHAM, Stanley, care of E. Burnett, 11 E. 24th St., New York, N. Y.
CUTTER, H. F., care of Northern Texas Traction Co., Fort Worth, Tex.
CUTTING, C. J., 25 Front St., Schenectady, N. Y.
DAGGETT, F. W., care of Ransome Concrete Machinery Co., 11 Broadway, New York, N. Y.
DANIELSON, WHITMAN, 104 Jay St., Schenectady, N. Y.
DAVOL, F. H., Jr., 75 Remsen St., Brooklyn, N. Y.
DAY, PAUL, Hopedale.
DIAZ, M. D., E and 23rd Sts., Vedado, Havana, Cuba.
DINSMOOR, R. P. J., 1748 Broadway, Denver, Colo.
DOE, E. I., 119 Robbins St., Waltham.
DOW, C. S., 24 Milton Sq., Hyde Park.
DROWN, R. W., 37 Phillips Ave., Lynn.
DUBOIS, DELAFIELD, 514 Smith St., Schenectady, N. Y.
DURANT, ALDRICH, care of Turner Construction Co., 11 Broadway, New York, N. Y.
DURWARD, ARTHUR, 255 East Pasadena St., Pomona, Cal.

Edwards, D. G., 417 W. 120th St., New York, N. Y.
Emery, Manning, Jr., Le Roy Cotton Mills, Le Roy, N. Y.
Francis, J. S., 7434 Boyer St., Philadelphia, Pa.
Gardner, J. E., 222 Benton St., Aurora, Ill.
Garfield, C. A., 19 Norman St., Cambridge.
Gilson, A. P., Wellesley.
Gould, C. M., Cold Spring, N. Y.
Greenlaw, R. W., Cold Spring, N. Y.
Hale, H. M., 417 W. 120th St., New York, N. Y.
Harrison, E. S., care of American Diesel Engine Co., 11 Broadway, New York, N Y.
Harrison, James, Kinloch Bldg., St. Louis, Mo.
Haskell, A. L., care of National Carbon Co., Cleveland, O.
Hauck, William, Brewster, N. Y.
Henry, G. S., 307 McPhee Bldg., Denver, Colo.
Hodges, A. W., 23 Kenwood Ave., Newton Centre.
Hogan, J. P., High Falls, N. Y.
Holland, C. M., 215 W. 23rd St., New York, N. Y.
Horne, H. W., Cornwall-on-Hudson, N. Y.
Hughes, H. J., 6 Clement Circle, Cambridge.
Jackson, H. A., 1018 Fisher Bldg., Chicago, Ill.
Jenson, Joseph, Logan, Utah.
Johnson, Granville, 79 Bellevue St., Boston.
Jones, E. L., 4 Grand St., White Plains, N. Y.
Jones, I. T., care of Westinghouse, Church, Kerr Co., 10 Bridge St., New York, N. Y.
Kennedy, F. L., 43 Appleton St., Cambridge.
Keyser, G. D., P. O. Box 754, Salt Lake City, Utah.
Kimball, G. C., Frick Bldg., Pittsburg, Pa.
King, Moses, Jr., 404 West 115th St., New York, N. Y.
Klein, S. M., 1610 St. Paul St., Baltimore, Md.
Lewis, J. R., care of Crocker-Wheeler Co., 607 Empire Bldg., Pittsburgh, Pa.
Libbey, J. H., 14 Parsons St., West Newton.
Locke, J. P., 119 Fisher Ave., White Plains, N. Y.
Massa, R. F., 122 Augusta St., Chicago, Ill.
McAvity, A. G., care of Canadian Buffalo Forge Co., Montreal, Canada.
McGrath, W. H., Houghton, Mich.
Merryweather, A. M., care of Brown Hoisting Machinery Co., Cleveland, O.
Milinowski, A. S., 411 East Erie Ave., Lorain, O.
Mills, C. W., Clark & Mills Co., Cambridge.
Monks, A. G., 20 Central St., Boston.
Moore, H. B., 1 W. 72nd St., New York, N. Y.
Morse, A. H., 16 Kirkland Rd., Cambridge.
Moses, P. L., Stoughton Gas & Electric Co., Stoughton.
Moyer, J. A., 214 Ocean St., Lynn.
Mumford, G. S., Cold Spring, N. Y.
Nash, Herbert, Jr., care of Tampa Electric Co., Tampa, Fla.
Norton, Clifford, 1000 Hill St., Hannibal, Mo.

OLDS, N. E., 1240 Washington Boulevard, Fort Wayne, Ind.
PARTRIDGE, WARREN, 100 Chestnut Ave., West Orange, N. J.
PERCIVAL, A. W., 523 Mooney-Brisbane Bldg., Buffalo, N. Y.
PERRY, J. P. H., care of Turner Construction Co., 11 Broadway, New York, N. Y.
PETTEBONE, L. A., American House, Schaghticoke, N. Y.
POOR, F. H., 241 Liberty St., Schenectady, N. Y.
POWNALL, W. A., C. B. & Q. Laboratory, Aurora, Ill.
PURCELL, H. W., 463 Central Park West, New York, N. Y.
ROGERSON, R. C., 77 Centre St., West Lynn.
ROSS, LOUIS, care of U. S. Reclamation Service, Washington, D. C.
ROTCH, WILLIAM, Jr., 157 Bay State Road, Boston.
RYAN, M. H., 231 W. 125th St., New York, N. Y.
SHAUGHNESSY, C. S., 1307 Main St., Peekskill, N. Y.
SHERTZER, T. B., 38 State St., Portland, Me.
SIDDALL, JOSEPH, 355 W. 14th St., New York, N. Y.
SLOCUM, C. L., 314 Railroad Bldg., New Haven, Conn.
SMITH, E. N., New Paltz, N. Y.
SPALDING, P. L., 315 So. 18th St., Philadelphia, Pa.
SPENCER, W. A., 2 Craigie St., Cambridge.
STARK, C. W., 1215 Grand Central Station, New York, N. Y.
STONE, E. C., 14 Race St., Swissvale Sta., Pittsburgh, Pa.
STONE, W. M., Summer St., Waltham.
STURGES, H. W., 61 Oxford St., Cambridge.
STURGIS, ARTHUR, 79 Cypress St., Brookline.
SWENDSEN, G. L., Provo, Utah.
TAYLOR, W. E., Jr., 1116 Indiana Ave., LaPorte, Ind.
THANISCH, R. J., 151 Park St., West Roxbury.
THAYER, N. A., 420 W. 121st St., New York, N. Y.
TILDEN, C. J., New Engineering Bldg., Ann Arbor, Mich.
TOWLE, FOSTER, care of U. S. Reclamation Survey, Fort Shaw, Mont.
TRAIN, A. H., 25 Front St., Schenectady, N. Y.
TUCKER, H. F., care of Isthmian Canal Commission, Washington, D. C.
TYNG, ARTHUR, 325 Beech St., Morris Park, L. I.
VAUGHAN, E. A., care of National Carbon Co., Cleveland, O.
WADSWORTH, L. L., 53 State St., Boston
WALKER, R. S., care of Kelly Trust Co., Fort Smith, Ark.
WARD, H. C., Greenfield, Tenn.
WARE, JOHN, 23 Ellsworth Ave., Cambridge.
WHITE, O. C., Jr., 8 Shepard St., Worcester.
WHITING, S. E., 11 Ware St., Cambridge.
WHITNEY, G. B., 8 Greenwood Ave., Swampscott.
WHITON, H. S., care of Ponce Railway & Light Co., Ponce, P. R.
WILLIAMS, H. T., 1445 Massachusetts Ave., Washington, D. C.
WILSON, J. A., 413 First St., Brooklyn, N. Y.
WILT, A. D., 525 Jefferson Ave., Detroit, Mich.
WOOD, J. W., Jr., 367 Harvard St., Cambridge.

Graduates who have not sent in Addresses, February–March, 1907.

(So far as addresses which are almost certainly correct are known, they have been put down, for possible amendment.)

ALBRIGHT, LANGDON.
ALEXANDER, H. J.
ALLYN, R. B., 11 Berkeley St., Cambridge.
ARENSBERG, F. L.,
BAKER, M. H.
BAKER, C. H.,
BASSETT, A. W.
BLAKE, R. F.
BORLAND, BRUCE, 2616 Prairie Ave., Chicago, Ill.
BROWN, FRANCIS.
BULL, R. W., Palmerton, Pa.
BULLEN, ROY, Richmond, Utah.
BUNTING, R. A.
BUNTON, G. H.
BUTLER, J. A.
CAMPRUBI, JOSÉ, care of N. Y. C. & H. R. R. R., New York, N. Y.
CHAPIN, A. G.
CHASE, J. D., 139 Border St., Dedham.
CLARK, T. W.
CLARKE, J. G.
CLOUD, F. W.
COBURN, H. B., Jr.
COOLIDGE, J. W.
COUTANT, J. K.
CRANE, R. T.
CUTLER, S. C.
DAVIS, E. G., Interborough Rapid Transit Co., 21 Park Row, New York, N. Y.
DAVIS, N. K.
DAVIS, P. W.
DEBLOIS, L. A., care of California Powder Co., Wells-Fargo Bldg., San Francisco, Cal.
DENSMORE, E. D., 15 Exchange St., Boston.
DUDLEY, J. C., 604 Whitney Ave., Wilkinsburg, Pa.
DUSTIN, G. H.
EAMES, H. L.
EATON, J. J., Box 589, Manila, P. I.
EAYRS, T. C.
EDGELL, F. V.
EICHORN, F. C. H.
ELLIS, S. G.
EVELETH, C. M.

FARNHAM, H. S., 215 W. 23rd St., New York, N. Y.
FERGUSON, R. A.
FIELD, S. B.
FISHER, C. H., 14 Union Depot, Ogden, Utah.
FITZHUGH, E. H., Jr.
FOX, H. H., care of Turner Construction Co., New York, N. Y.
FOX, PHILLIP.
FRANCIS, R. S.
FROST, V. M.
FURNESS, D. L.
GERRISH, G. H.
GILMAN, CHARLES.
GITTINGS, H. M.
GOULD, W. M., 16 Russell Road, W. Somerville.
GRIFFIN, W. M., care of P., N. Y. & L. I. R. R., New York, N. Y.
HACKETT, L. A., 34 Pearl St., Chicopee.
HACKLEY, J. G.
HANAVAN, W. L., 42 Market St., Poughkeepsie, N. Y.
HANSEN, N. M.
HANSON, C. T.
HARRIS, ALBERT, Art Metal Construction Co., Jamestown, N. Y.
HAWKS, A. S., Greenfield.
HAZARD, L. P., care of Cincinnati Traction Co., Cincinnati, O.
HEDRICK, W. A.
HENDERSON, J. F.
HOLMES, G. E.
HOPKINS, S. U.
HOWE. H. A., care of Dept. U. S. Geol. Survey, Lujane, Montrose Co., Colo.
HOWES, D. W.
HUGHES, H. L., U. S. Steel Products Export Co., 21 State St., New York, N. Y.
HUNTING, E. N., 4 Smithfield St., Pittsburg, Pa.
JENSON, J. W., Logan, Utah.
JOHNSON, A. N.
JONES, W. St. C.
JOPLING, M. W., Marqueete, Mich.
JOYCE, L. V.
KATIGBAK, J. P., Lipa, Batangas, P. I.
KELSEY, W. H., 309 Electric Bldg., Cleveland, O.
KERNAN, H. D.
KIMBALL, A. C.
LEE, C. C., care of Baldwin Locomotive Works, 1316 Spruce St., Philadelphia, Pa.
LEWIS, F. C.
LINDSLEY, THAYER.
LUPIEN, U. J., care of General Electric Co., Lynn.
LUSCOMB, H. M.
LYMAN, C. F.
MAREAN, P. E.

McClinton, D. N., 7130 Monticello St., Pittsburg, Pa.
McElligott, J. J. T.
McNary, C. H.
Meadowcroft, W.
Meadows, H. G., Prudential Bldg., Buffalo, N. Y.
Meier, C. R. D.
Montague, S. S.
Montoulieu de Latorre, H., Apartado 7, Ciego de Avila, Cuba.
Morgan, Henry.
Morris, D. H.
Moses, E. Q.
Moses, E. M.
Moses, H. W.
Moynahan, J. J.
Newell, G. R.
Newhall, F. W.
Noyes, S. H., 15 Francis St., Newport, R. I.
Outerbridge, F. R., 39 Broadway, New York, N. Y.
Outerbridge, S. R., 39 Broadway, New York, N. Y.
Page, J. H.
Patterson, P. M., 28 Hillside Ave., Arlington Heights.
Peirce, R. K.
Peper, E. C.
Perry, C. R.
Pierce, H. C., American Ball Engine Co., Bound Brook, N. J.
Pierpont, Lawrence.
Piper, W. T.
Pollak, R. R.
Pope, Frederick, Harvard Club, New York, N. Y.
Pratt, F. S.
Presby, G. W.
Proudfoot, A. S.
Rand, R. B.
Raudenbush, H. W.
Rich, W. S.
Richardson, F. A.
Robinson, F. D.
Rockwell, S. F.
Ruland, N. M.
Saldaña, E. E., San Juan, P. R.
Saldaña, M. A., San Juan, P. R.
Sawin, G. A., care of General Electric Co., Lynn.
Seaver, Clifford, Penna. Terminal Engr. Office, 225 W. 33rd St., New York, N. Y.
Selfridge, Harold.
Sheldon, A. N.
Sherburne, Kenneth, 363 Marlboro St., Boston.
Shore, H. E.

SIMPSON, T. W.
SMITH, ALLAN, Cold Spring, N. Y.
SMITH, E. H.
SMITH, H. W.
SNOW, CLARENCE.
SNYDER, A. L.
SOUTHER, A. B.
STETSON, H. N., Mt. Pleasant St., St. John, N. B.
STEVENS, CABOT.
STEVENS, E. A., Jr.
STEVENS, SIDNEY.
STEVENSON, W. F., Rapid Transit Commission of New York, 4 Court St., Brooklyn, N. Y.
STEWART, J. R.
SULLIVAN, R. T.
TALPEY, A. H. E.
TAYLOR, G. F.
TERBUSH, M. E.
THAYER, A. A., 304 Oak St., Cincinnati, O.
THAYER, C. S.
TIRRELL, C. E., 1170 Broadway, New York, N. Y.
TOLMAN, S. A.
VERVEER, EMANUEL.
VOSS, A. B.
WEITZE, C. R.
WEITZEL, N. T., 52 William St., New York, N. Y.
WELLS, P. A.
WHEELER, H. C., Peterboro, N. H.
WHITE, BRYANT.
WHITE, R. A., care of Ford, Bacon & Davis, New York, N. Y.
WHITTIER, E. J.
WHITTLESEY, E. B.
WHORF, S. C.
WILCOCK, FREDERICK, 231 W. 125th St. New York, N. Y.
WILLIS, E. N.
WINTER, J. B.
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WRIGHT, D. C., care of Electric Controller & Supply Co., Cleveland, O.

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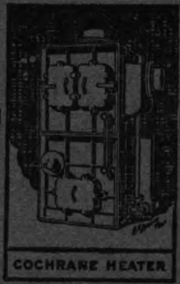
The older methods of drying material by direct steam and natural circulation of air are rapidly giving way in these strenuous days to indirect systems in which fans are employed to greatly facilitate the rate of drying. The prevalence and diversity of such systems are well illustrated by recent orders taken by the B. F. Sturtevant Co., of Boston, Mass., for such hot blast drying equipments as the following: Opaque Shade Cloth Co., Chicago, Ill., for drying shade cloth; bark drying equipment for Manetto Extract Co., Key West, Fla.; installations in connection with rotary rubber dryers for Manufactured Rubber Co., Methuchen, N. J.; wallpaper drying apparatus for Pittsburg Wallpaper Co., New Brighton, Pa.; special soap drying equipment for Munyon's Homeopathic Home Remedy Co., Philadelphia, Pa.; apparatus for use in connection with special paint product drying tunnels for Krebs Pigment & Chemical Co., Newport, Del.; leather drying equipment for tannery of J. K. Mosser Co., Noxen, Pa.; hot blast apparatus for veneer drying machines for The National Veneer Products Co., Mishawaka, Ind.; and soap drying apparatus for tentering machines for the H. W. Butterworth & Sons Co., Philadelphia, Pa.

In all these installations the entire heating surface, which is much less than would be required with direct radiation, is enclosed in an independent steel plate casing through which a fan draws the air. The air thus heated is forced through or across the material to be dried.



$100 for the Best Theses

We shall distribute $100.00 in prizes of $50.00, $25.00, $15.00, and $10.00 for the best four theses prepared by '07 graduates embodying designs of new steam plants, or complete descriptions or tests of existing plants, with suggestions for improving the methods of handling steam or water therein.

These theses are to be submitted to us before July 1st, 1907, and are to be duplicates of the copies turned in to the faculty. In passing upon their merit we shall give first importance to the following features:

1. Good judgment in the selection and arrangement of apparatus for the conditions involved.
2. Accuracy and thoroughness in pre-determining quantities and proportioning apparatus.
3. Effectiveness and lucidity in discussing the proposition, stating the reasons for choice, etc.

This competition is open to all 1907 graduates in all technical schools in the United States. The winners of this contest will be announced in Power for September, '07.

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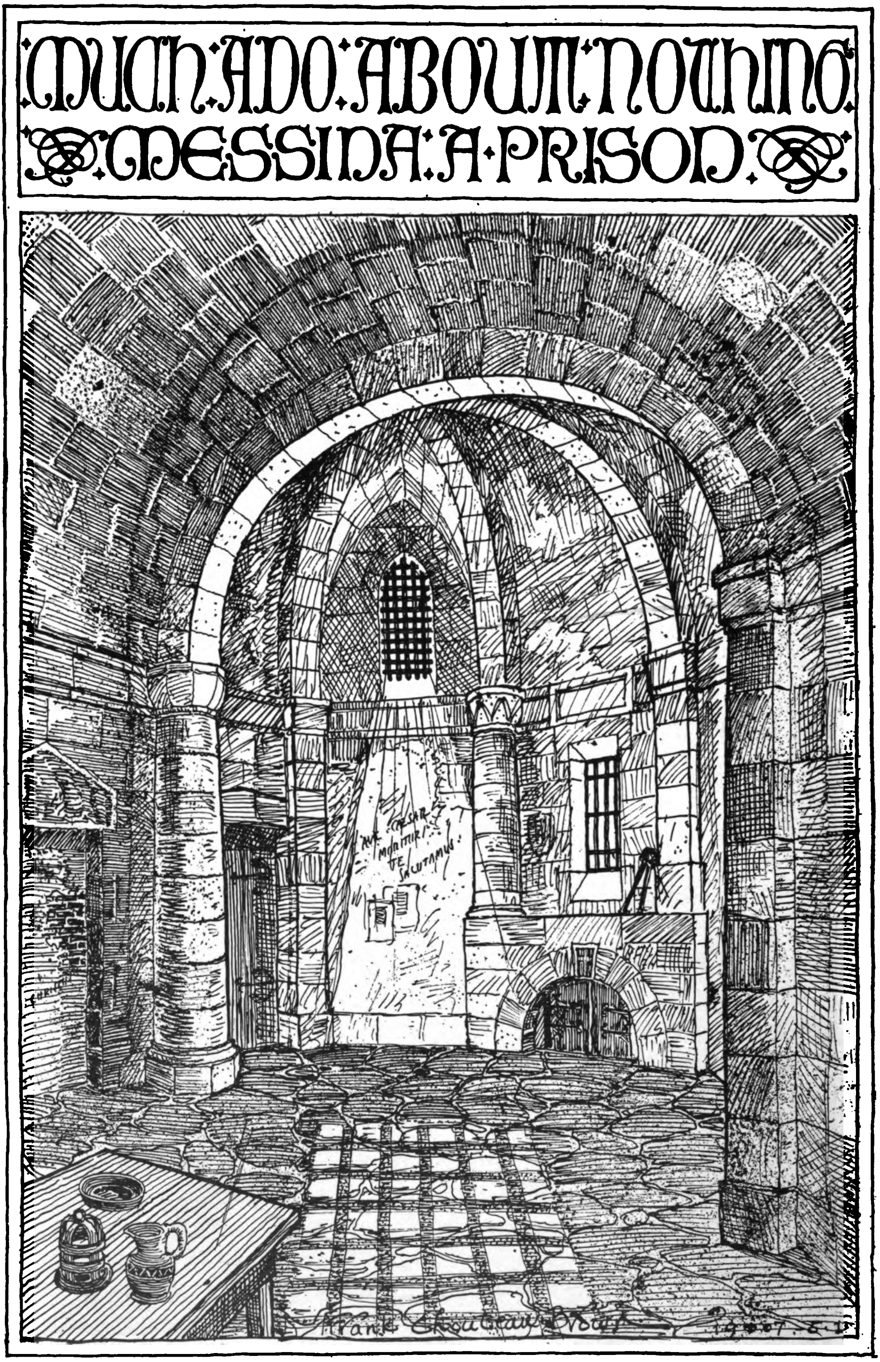
JUNE, 1907

HARVARD ENGINEERING JOURNAL

A QUARTERLY
DEVOTED TO THE INTERESTS OF
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

Vol. VI TABLE OF CONTENTS No. 2



(See p. 11.)

HARVARD ENGINEERING JOURNAL

A QUARTERLY

Devoted to the interests of Engineering and Architecture of Harvard University

VOL. VI JUNE, 1907 NO. 2

THE PREPARATORY PERIOD, PANAMA CANAL.

BY GENERAL HENRY L. ABBOT.

The New Panama Canal Company transferred its rights and properties to our Government on May 4, 1904, and popular opinion in the United States demanded the immediate beginning of operations upon a large scale. This was most unreasonable. Not only was it necessary to recruit and organize an immense laboring force, and to provide the needful supplies and buildings for its occupation, together with plant of modern patterns for the prosecution of the work, but it was also obligatory to bring about a radical improvement in the sanitary conditions on the Isthmus before introducing an army of unacclimated persons into a region where previous experience in the construction of the Panama Railroad and in the tentative operations of the first French Company had left a ghastly record. The necessity for these preparatory measures at the outset was more or less appreciated by the sensible public, although the press teemed with groundless protests at the delay in "making the dirt fly"; but in truth there was another reason even more potent than the above for slow progress in actual construction. This reason, appreciated but by few, was the fact that a definite project for the canal had to be adopted before it was possible judiciously to plan work on a large scale. Such a project was not even approximately formulated until June 29, 1906, when action was finally taken by Congress after a long delay caused by the revival by the first Chief Engineer, Mr. Wallace, of the old de Lesseps idea of a sea level construction. A canal of this type had been condemned by every French

and American Engineer Commission since the disastrous failure of 1888; and if due weight had been given to their conclusions, based on elaborate study of the physical conditions existing on the Isthmus, the work to-day would be much further advanced. One must know the depth of the cut before deciding the width at top, upon which will depend both an economical placing of the plant and a wise selection of the dumps. For twenty-six months the fundamental elements of the project were undecided; but advantage was taken of this enforced delay to push forward vigorously the needful preparations, and now actual construction is beginning on a large scale. In last March, 815,270 cubic yards were taken out, and work on the Gatun group was beginning. In April the total figures were 987,527, 108,000 being at Gatun. It should not be forgotten, however, that the end of the dry season is approaching, and that a small reduction in this recent output is not improbable.

Before considering matters of technical interest a brief summary of events since the work passed under the control of the United States seems appropriate, although treated at some length in this JOURNAL in the number for April, 1906.

The law of June 28, 1902, devolved upon the President the duty of constructing the Canal, acting through a Commission of seven members. He placed the work under the immediate supervision of the Secretary of War. The Commission, under Admiral Walker as Chairman, was organized about a month before the transfer of the property on May 4, 1904, and lost no time in visiting the Isthmus and beginning operations. In addition to its special canal duties this Commission was charged with legislation for the provisional government of the Zone, which added no little to its labors and responsibilities, especially as this authority must terminate under the law on March 4, 1905. Twenty-four laws, covering a wide range of subjects, were enacted. Another onerous duty was the administration of the Panama Railroad, including its ocean fleet. This duty was assigned to the Commission acting under the laws of New York as members of the Board of Directors to represent the shares (nearly all) owned by the Government. The canal duties proper proved to be no sinecure, involving surveys and investigations to determine a project suited to the new condi-

tions as a national undertaking; the creation of an organization to administer an immense work distant 2,300 miles from its base of supplies; the sanitation of the Zone, including a water supply for and the cleaning of the cities of Panama and Colon; the repair of many old and the construction of many new buildings; the formation of new docks and new freight yards for the railroad; and the purchase of new and the repairs of old plant left by the French.

On April 1, 1905, the President dissolved this Commission and appointed a new one, of which Mr. Theodore P. Shonts was Chairman, Mr. Charles E. Magoon was Governor of the Zone, and Mr. John F. Wallace was Chief Engineer. All administrative duties were confided to these gentlemen, those of the remaining four members being of a revisory and technical character. The yellow fever reappeared on the Isthmus in 1905, the panic reaching its height in June and July, but it was soon suppressed by the sagacious and vigorous measures adopted by Colonel Gorgas, and no cases have occurred since the autumn of that year.

Mr. Wallace tendered his resignation as Chief Engineer in June, 1905, and was promptly replaced by Mr. John F. Stevens, who has subsequently discharged the responsible duties of the office most efficiently.

In June, 1905, the President appointed an international Board of Consulting Engineers, thirteen in number, to assemble at Washington on September 1, for the purpose of considering and advising upon the various projects for the canal proposed by or to the Isthmian Canal Commission. General George W. Davis was designated its Chairman. The Board inspected the works on the Isthmus, studied the voluminous data presented for its information, and finally submitted its report early in February, 1906. A difference of opinion had developed, and two reports were drafted. That of the majority, which included the five foreign members and the three American members who when serving on the former Commission had adopted Mr. Wallace's sea level views, favored a canal of that type; the others advocated a canal with locks, which would afford easy lake navigation for nearly the entire distance from ocean to ocean, and would effectually control the vagaries of the Chagres. The

President promptly forwarded the report to Congress, the project of the minority having the favorable indorsement of himself, of Secretary Taft, of the Commission, and of Mr. Stevens, the Chief Engineer. After an extended discussion in the Senate and House this project was adopted, and thus became the official type for the Canal, receiving the approval of the President on June 29, 1906.

During this session of Congress the question of hours of labor also came up for consideration. The Attorney-General had decided that the eight-hour law applied to the Isthmus, his decision taking effect on June 1, 1905. Ten hours had always been the rule, and this added twenty per cent. to the working cost. An amendment to the urgent deficiency bill provided that the eight-hour law should not apply to alien labor on the Isthmus, but as this did not include the needful supervision it was manifestly ineffective, and such extension was granted in a later act; but as the skilled labor needful for the simultaneous operation of the plant was not included, the practical effect of the legislation has not been what is greatly to be desired for rapid progress; namely, the continued use of a ten-hour day, always the rule heretofore.

Finally, the question whether the work shall be done by contract or by day's labor presented itself. Mr. Stevens favored the former mode, and drafted a memorandum which after some modification resulted in the advertising for bids upon a profit basis. Four were submitted in January, 1907, ranging from 28 per cent. to 6.75 per cent. on estimated cost, but it was ultimately decided to make no award. Secretary Taft, in a recent address, stated the reason: "We found that it would be necessary for the contractors to have the help of capitalists and we would be compelled to allow the contractors seven per cent. interest on the money they would be compelled to borrow from the capitalists. As we could borrow money at two per cent., this seven per cent. proposition did not appeal greatly to us."

In November, 1906, the President made a personal inspection of the works on the Isthmus, and in a special message to Congress, expressed his satisfaction at the progress noted. In an executive order, issued while on the spot, he made some im-

portant changes in the local administrative system, creating seven executive departments, comprising that of Chief Engineer, of General Council, of Chief Sanitary Officer, of General Purchasing Officer, of General Auditor, of General Disbursing Officer, and of Manager of Labor and Quarters.

Very recently there has been another complete reorganization of the Isthmian Canal Commission, brought about by the resignations of Mr. Shonts and Mr. Stevens. The third Commission, just appointed, and of which all the members will reside on the Isthmus, consists of Lieut. Col. George W. Goethals, Corps of Engineers, Chairman and Chief Engineer; Major David DuB. Gaillard, Corps of Engineers, excavation and dredging; Major William L. Sibert, Corp of Engineers, locks, docks and dams; Rear Admiral H. H. Rousseau, Civil Engineer, U. S. Navy, mechanical department; Col. William C. Gorgas, U. S. Army, sanitary affairs; Mr. Jackson Smith, labor department; and Hon. Joseph C. S. Blackburn, Governor of the Zone. This change virtually devolves the direction of the work upon officers of the Corps of Engineers, as was contemplated by Senator Spooner in drafting the bill authorizing the purchase of the property of the New French Canal Company, but which was changed to a Commission of seven members by an amendment introduced in the discussion before the Senate.

Mr. Stevens has created a very efficient organization. The preparatory work in the way of sanitation, water supply, buildings for the laboring force, canal equipment, new tracks, new dockage, and new running stock for the railroad, etc., is essentially completed; and there is reason to anticipate much more rapid progress in the future. At the end of last January, 4,426,212 cubic yards had been removed, at an average cost of 78.4 cents. It may be a little surprising to note that this unit cost considerably exceeds what was paid by the New French Company for work executed with their old plant. From January 1, 1896, to June 30, 1897, they took out 1,313,665 cubic yards, at a cost of 55.3 cents, carefully recorded as a basis for their estimates. This was taken from what is now called the Culebra Cut, but which was then subdivided into the Culebra and the Emperador Cuts, the former name being restricted to

about two miles of the deepest cutting. This greater American cost is partly explained by the introduction of an eight-hour day upon the Isthmus, and probably higher wages must account for the difference in outlay, for the plant in use is all modern.

Summing up present conditions, it is gratifying to note that under the wise administration of Colonel Gorgas the health of the Zone has wonderfully improved, and that notwithstanding the advent of some 30,000 laborers on the canal and railroad the percentage of sickness and death differs little from that in an average healthy locality in the United States. The labor question is still unsettled. At present, aside from the skilled artisans, the work is almost entirely done by West Indian negroes, of whom the efficiency is very low. Mr. Stevens states in his last annual report: "The majority work just long enough to get money to supply their actual bodily necessities, with the result that while we are quartering and caring for twenty odd thousand of these people, our daily effective force is many thousands less." Very promising experiments, however, are making with laborers from the northwestern provinces of Spain, of whom considerable numbers have been employed with marked success. Colonel Gorgas wrote last September: "The death rate among the negroes is large, increasing for the last six months by the prevalence of an epidemic of pneumonia, which has just begun to subside. But for one reason and another they have not the stamina that the whites have, and suffer in all directions more than do the whites." This indirectly illustrates the benefits of sanitation, for formerly experience showed the reverse.

Coming now to matters of more technical interest to engineers, the accumulation and analysis of data having a bearing upon the project for the canal have not been neglected since the work passed under the control of the United States. Borings and surveys have been multiplied to elucidate the new problems which have arisen. Meteorology and River Hydraulics have been consolidated in a special Bureau of the Engineer Department, under the direction of a division engineer, Mr. Ricardo M. Arango, who has given systematic and intelligent attention to the collection and discussion of data covering the

past three years. As to the general results it suffices to state that the epoch of moderate rainfall and river discharge which characterized the later years of the French operations still continues; but that a very large flood of the Chagres occurred last December, and was successfully measured at all three of the most important stations, Alhajuela, Gamboa and Bohio. These records merit special attention.

During the half century since the completion of the Panama Railroad there have occurred only six great floods, those of 1879, 1885, 1888, 1890, 1893, and this last one. Concerning the first, the water heights attained at several important localities alone were preserved; the flood of 1893 was systematically measured, but unfortunately it was the least formidable of any; valuable observations were taken on all the others, especially at Gamboa, where the river joins the canal route, and at Bohio, in 1890; but as it was certain that the volume in 1879 must have largely exceeded that in any of the others, the engineers of the New Company were compelled to adopt it as the standard, and to estimate its volume as best they could by an analysis of the records of those of later date. This recent flood was much larger than any of the preceding, except that of 1879, and so nearly approached the later as to abundantly justify the estimates of its volume and consequently of the measures judged needful to protect the canal route against damage. This is apparent from the following figures:

Maximum flow at Gamboa in 1906	76,000 ft.-sec.	Height above low water	35.7 ft.
Estimated flow in 1879	78,600 "	" " " "	36.7 "
Maximum flow at Bohio in 1906	108,000 "	" " " "	38.7 "
Estimated flow in 1879	112,700 "	" " " "	39.4 "

This comparison demonstrates that the recent flood so nearly approached the extreme limit that the circumstances surrounding it possess special interest. It was preceded by a first class freshet, caused by heavy rains, on November 15, 16 and 17, which produced a brief maximum flow of 43,100 feet-seconds at Alhajuela, of 40,100 at Gamboa, and of 46,300 at Bohio. The lower tributaries thus contributed largely to the flow, and the basin was deluged and ill prepared to receive the steady downpour which followed almost from day to day. Thus, on December 3, the rainfall at Alhajuela was 5.16 inches, at Gamboa 3.71 inches, at Bohio 3.59 inches and at Colon 4.75

inches. These cloud-bursts falling upon a district already inundated, caused the great flood of which the water heights and volumes are shown in the above table, and of which the date at Alhajuela and Gamboa was December 3, and at Bohio, December 4; as usual, the river subsided rapidly. About fifteen miles of the main line of the Panama Railroad were submerged from two to ten feet, and water stood on the track at Matachin five feet deep. Two small bridges were carried away, and naturally, canal operations suffered interruption. Duration as well as maximum flow must be considered in comparing floods, and perhaps the best standard is the reservoir capacity above Bohio, needful to protect the canal route below from interference. For the recent flood, which was rather short, this was 129,000 acre-feet; for the flood of 1879 it ranged between 144,000 and 193,000 acre-feet, according to its probable duration as compared with those of the known floods. The engineers of the New Company adopting a large safety coefficient assumed it at 203,000 acre-feet; this new flood thus amply confirms the sufficiency of the previsions.

Another matter is not without interest in comparing the old and new data,—do the latter sustain the conclusions reached as to the ultimate disposal of rainfall in the basin above Bohio? These researches were undertaken and continued for six consecutive years with a view to throwing light upon the question of possible seepage from the artificial lakes to be created. On the Isthmus the absence of ice and snow, the small annual variation in temperature and humidity, and the regular succession of rainy and dry months has greatly facilitated the study of the ratio between downfall and outflow. The six-year records indicated that this ratio had its minimum value in May, at the end of the dry season, being then about 0.30; that it gradually and regularly increased as the rainy months succeeded each other, attaining a value of about 0.75 in November, when the rainfall reached its maximum; then passed through fictitious values above unity in the dry season, reaching a maximum in February; then fell gradually to the minimum in May. This sequence demonstrates that the river receives large contributions from ground water, and hence that no danger exists of any important escape through subterranean fissures in

the basin. Indeed, during the dry months the flow is chiefly due to ground water, and without it the stream would run nearly or quite dry as do many of its tributaries at this season. Space is lacking to consider the analysis leading to these conclusions, but the final result of the study of the six-year records indicated that roughly one-third of the annual rainfall disappeared in evaporation, plant absorption, etc., one-third passed off directly by the channel of the river, and the remaining third, after a delay of perhaps two or three months, reached it as ground water. These deductions have been amply verified by the observations directed by Mr. Arango during the past three years.

So much interest attaches to researches of this character from their bearing upon irrigation, the water supply of cities, generation of power, etc., and so few data have been accumulated in the tropics, that it has seemed proper to give in the following table the average figures derived from these nine-year records. The rainfall in inches and the outflow in inch miles are directly comparable; the outflow in feet-seconds is added as being the more usual unit. As the mathematical solecism of averaging ratios is not uncommon, it may be stated that the mean monthly values here given represent the means of the totals involved. The total flow is that measured at Bohio, where all outflow from the 700 square miles of the basin passes. The direct flow is estimated by multiplying this quantity by the quotient of 0.30 (the minimum ratio) by the observed value for the month in question. The ground water flow is the difference between these two volumes. It passes through a minimum in May and a maximum in November, and its gradual and progressive changes are what might be expected in water percolating through the ground,—quite different from the direct flow which is dependent for its supply upon the varying rainfall. Evaporation is represented by the difference between rainfall and total outflow in inch miles, but in the lack of knowledge as to the rate of flow of the ground water the monthly values are not comparable. The annual value, representing a complete cycle, should be correct. In figures it is 38.29 inches, or expressed in the usual unit per 24-hours 0.105 inches. This represents the general evaporation from the whole

surface of the basin, which is, of course, less than that from exposed water surfaces. Experiments have been begun by Mr. Arango to measure the latter by the pan method, and his results show for last December 0.135 inches, for January 0.167 inches, for February 0.181 inches, for March 0.211 inches, and for April 0.216 inches. These observations were taken at the reservoir at Bas Obispo, and seem to be confirmatory of the above annual figure for the general surface of the basin, deduced by a method so wholly different.

DISPOSITION OF RAINFALL ABOVE BOHIO
NINE YEARS, 1898-1906

Month	Ratio	Rainfall in Inches	Outflow in Inch Miles			Outflow in Feet-seconds		
			Grand Total	Direct Flow	Ground Water.	Grand Total	Direct Flow	Ground Water.
Jan.	1.12	5.24	5.86	1.57	4.29	3552	951	2603
Feb.	2.15	0.99	2.11	0.03	2.08	1420	20	1400
March	1.20	1.26	1.51	0.03	1.48	915	23	892
April	0.54	4.06	2.19	1.22	0.97	1374	763	611
May	0.33	11.19	3.65	3.32	0.33	2222	2020	202
June	0.45	10.84	4.87	3.25	1.62	3055	2037	1018
July	0.48	14.54	7.03	4.39	2.64	4269	2668	1601
Aug.	0.55	13.95	7.73	4.21	3.52	4687	2556	2131
Sept.	0.66	11.39	7.57	3.44	4.13	4743	2157	2586
Oct.	0.70	13.12	9.20	3.94	5.26	5585	2393	3192
Nov.	0.72	16.74	12.13	5.05	7.08	7613	3172	4441
Dec.	1.16	7.52	8.70	2.25	6.45	5288	1368	3920
Year	0.65	110.84	72.55	32.70	39.85	3727	1677	2050
3 dry	0.95	6.31	5.81	1.28	4.53	1236	269	967
9 rainy	0.63	104.53	66.74	31.42	35.32	4557	2147	2410

The question is often asked, when will the canal be completed? The works near Gatun and the cut through the continental divide fix the probable limit. In estimating the duration of the latter it is not uncommon to divide the total volume by the assumed annual output of the whole number of steam shovels provided. This is far from correct, for the real cause of delay is concentrated in about a mile of deepest cutting, and the number of shovels possible to employ here becomes less and less as the depth increases. Meantime, the greater part of the eight miles of cut will have been completed and much of the plant will have been standing idle. The official estimate of time of completion taking all circumstances into account was nine years, and we are now just beginning. Any gain will be an honor to the direction.

THE PREPARATION AND HANDLING OF A SHAKESPEARIAN PRODUCTION.*

BY FRANK CHOUTEAU BROWN, ARCHITECT.

As in all Shakesperian plays, the problem in designing the settings for "Much Ado about Nothing" was to reduce to the absolute minimum the time lost in changing the scenery between the acts. To prevent long waits between each scene was to allow the inclusion of that much more of Shakespeare's text, and so make it the nearer possible to give the play in its practical entirety within the three hours "traffic" of our modern stage. To effect this purpose, it was essential to conform the settings to a carefully worked-out scheme that often somewhat extensively governed their arrangement and disposition, and even occasionally exerted a certain restrictive influence upon their design; as may be more clearly evidenced by referring to the accompanying plans (Figs. 13 to 19, inclusive), showing the arrangement on the stage of each successive scene.

These plans of the stage sets are further explained by the several photographs of the principal settings, which were taken at the scene rehearsal the day before the first performance, when several pieces needed to complete the scenes yet remained to be painted. These plans and photographs, reinforced by the accompanying original studies for portions of two or three of the scenes, and the reproduced sketches for furniture and "properties," should enable any one interested to obtain a fairly complete comprehension of the difficulties presented by such a problem, and of at least a few of the means employed to produce the results described. Of the amount of canvas painted for this single play; the cost in dollars and cents of the production; of the research and time and thought expended upon the acting version and its rehearsal (the preparation of the scene models alone required over a hundred drawings, from among which those used to illustrate these articles were selected), it is quite impossible to give any adequate idea,—nor

*This is the third and last of a series of articles by the same writer. The first part, dealing with the general subject title, was included in the January issue; the second, more particularly describing and illustrating the "Much Ado about Nothing" settings, was published in the April number.

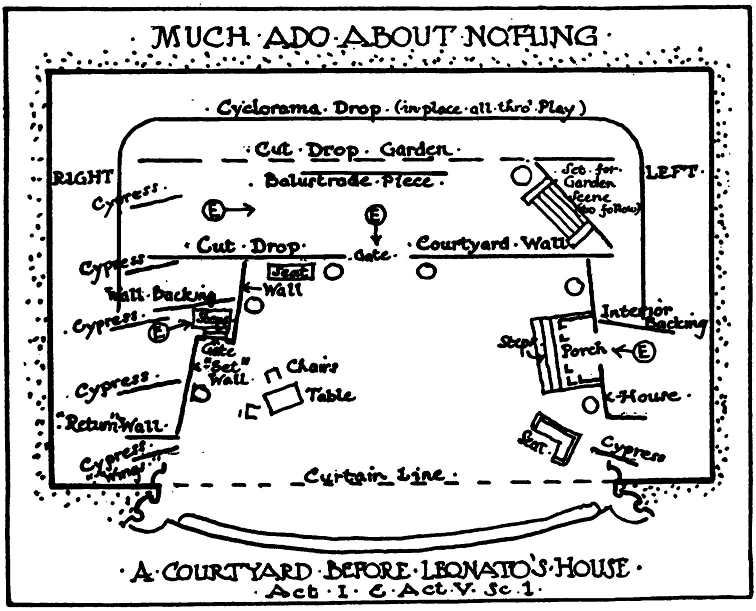


FIG. 13.

would it much advantage the unprofessional reader so to do, so essentially technical is the nature of the entire problem.

In many instances, the detailed sketches of portions of the scenes reproduce so as to better show their intention than appears in the photographs afterward taken from the actual—if still partially incomplete—settings. The treacherous scene-photograph is too likely to be absolutely barren of illusion—under even the best of circumstances; under conditions such as perforce governed the taking of these pictures, nothing except a record could or was to be expected. Bereft of their color; the effects of lighting; the groupings of actors in costume—that, in itself alone, would do much to "dress up" these bare stretches of the stage—they give but little idea of the depth and true effect of the stage pictures.

Beside the alternation of large and small, "deep" and "shallow," settings—a method that, as has previously been said, is distinctive of the Shakespearian production—an interesting experiment was ventured in this production in the use of two successive full stage scenes for the first and second acts. The

knowledge that a longer wait is more endurable by the audience after the first scene than at any later period in a play was taken into account in deciding to attempt this departure. The spectators are then still concerned in getting themselves comfortably settled. The story has hardly begun to move, and the auditors are yet but barely interested. Its continuity is therefore almost unbroken and, at the worst, but little injury done its dramatic effect.

Yet, to save all the time practicable, these first two scenes were so arranged that many of the same set pieces could be employed in both; some even remaining in their same positions upon the stage. (Figs. 13 and 14.) The garden waterpool, at the left, with all its drains and electrical connections, was set in place beneath the floor of the first act porch. The cypress wings at the right and all the "up stage" portions of the second act garden—including the heavy steps, platforms and buttresses of the important entrance above the fountain at the left (Fig. 4)—were set before the curtain arose on the first act; but were all partially or wholly hidden from the audience by the wall around these two sides of the first act courtyard.

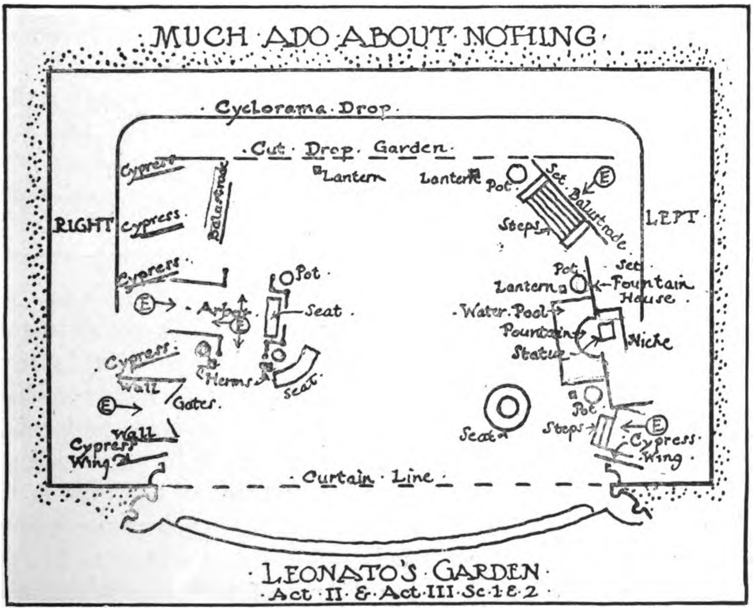


FIG. 14.

When the curtain fell on the first act, the set wall at the right was "struck," the arched gateway (Fig. 20) exchanged for the garden gate (Fig. 21) further "down stage," the porch and platform removed from over the pool and the fountain basin substituted. The figure and niche were placed from behind over the door opening, the courtyard drop raised, the trellised arbor shoved out upon the stage from the right and, by changing the furniture and other "props," the second scene and set were complete. Although so much was left undisturbed,

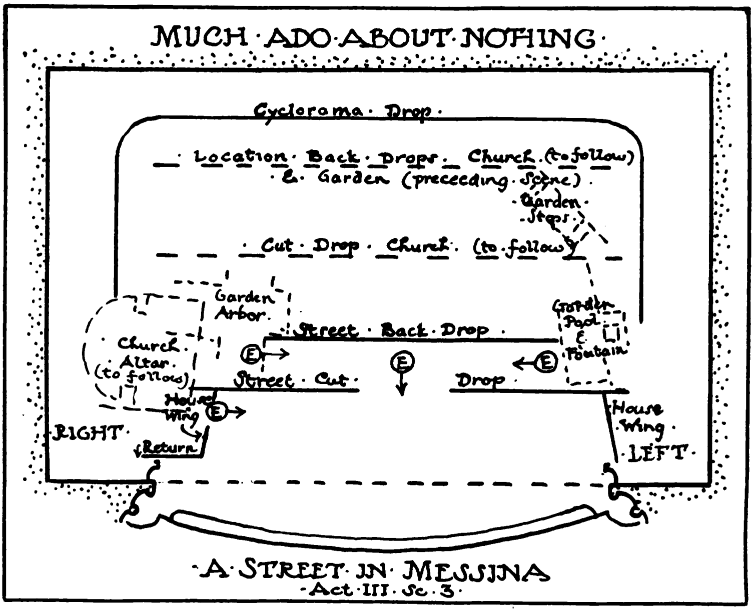


FIG. 15.

including the flats forming the house at the left, the entire picture was yet transformed quite beyond recognition in much less time than it would take to entirely set a new scene. While it is evident that this scheme could not often be so undertaken, yet, in this exceptional instance, it was so well disguised in its employment as to accomplish its purpose without permitting the audience to discover that any similarity between the two stage pictures actually existed.

In a production requiring the use of a "cyclorama drop"—in this case the cyclorama remained hanging throughout the

entire evening—or where so much of the full stage is used again and again, as in this series of settings, it becomes of great importance to do away with all the heavy and cumbersome pieces of furniture or platforms possible. The scene plans will show how little space is available at the sides, or remains behind the cyclorama drop at the back, in which to take care of these cumbersome pieces when they are not in use upon the stage. Furthermore, the sides of the stage are always crowded with huge stacks of scenery, leaning against the walls in apparently carelessly disposed, but actually carefully ordered, piles. The "grips" or stage hands, in using these wings and set pieces,

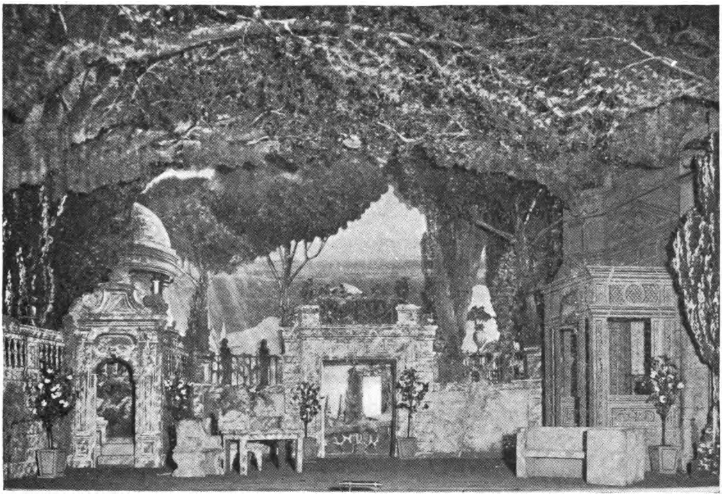


PLATE I.

transfer them from one pile to another according to a systematic method, so that each piece will always be found, when wanted, on the top of a "pack." After being used, it is then as regularly "flipped" over upon another stack, so that the pieces naturally come to the surface—night after night—in the same order in which they will be required.

With the sides given up to those cumbersome "packs," it is customary to place the built-up platforms, steps and other heavily constructed parts of the production along the rear wall of the theatre. This is, too, the only space where the property man's furniture may be safely accommodated and quickly and

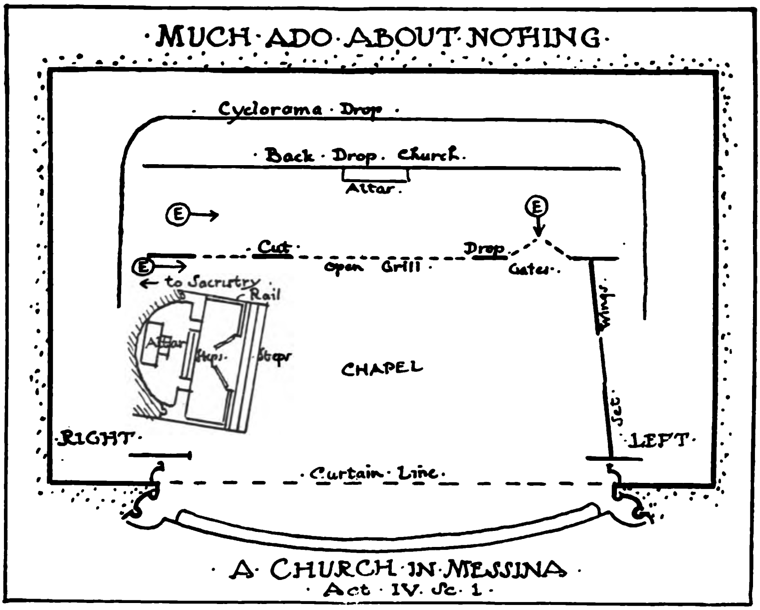


FIG. 16.

easily got at when needed. It is also necessary always to keep a clear passage across the stage behind this back drop to allow the actors to pass quickly back and forth during the action of the piece, and far enough away from it to prevent the canvas bellying out from the air displaced by their passing. While it is seldom that the use of platforms and steps can be altogether avoided in any heavily built production; yet if these heavy pieces can only be utilized upon the stage as some part of every scene, instead of cluttering up the little enough room left "off stage," and so hampering both the actors in getting about and the stage mechanics in handling the production, an almost ideal solution of the difficulty will be achieved.

The third setting (Fig. 15), "A Street in Messina," is formed of a "cut drop" and a narrow "back drop" hung close behind it, that can both be set by merely clearing away the centre of the stage and placing the house wings in the down stage entrances right and left. The preceding scene can then be "struck" and all of the following scene, the church interior, can be put in place, except the altar, while the street in Messina is in position.

The church setting (Fig. 16), which has already been described, is followed by the "prison" interior. (See Frontispiece.) Reference to the stage plans (Figs. 16 and 13) will show how well the arrangement of the latter (Fig. 17) was adapted to the elaborate church and courtyard settings between which it occurred. Occupying only a small section of the very centre of the stage, it allowed of all the following scene, including the heavy porch and house at the left, being set up while the elaborate altar piece at the right of the preceding

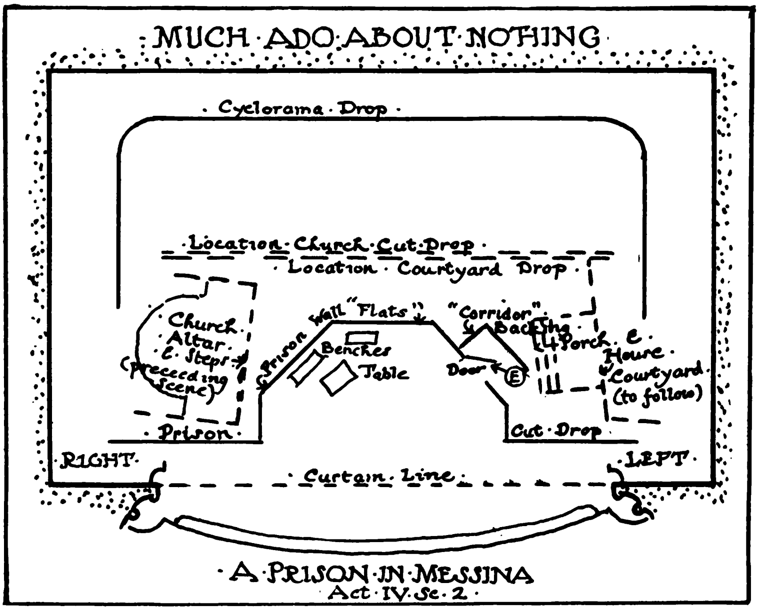


Fig. 17.

scene was being taken down; both being accomplished simultaneously while this shallow "front scene" was "on."

The arrangement of the last act of "Much Ado" is almost pre-eminently suited to meet the conditions imposed by a modern Shakespearian presentation. In any long-acting play, it is especially essential to retain the uninterrupted attention of the audience by having no waits of any length occur between acts or scenes at or near the end of the play. For every minute then wasted, the audience becomes more and more unsettled,

and more individuals are inclined to be restlessly gathering together their belongings and leaving the theatre to catch their final trains. Yet, that they may carry away a pleasant impression, it is equally important that the last set, especially, be lively and cheerful, and, if possible, novel in aspect.

In many ways the last scene of this "Much Ado" production was almost ideally fitted to solve the problem, although in its carrying out the idea was not as well developed as, with more time and preparation, would have been possible. The elaborate first set of the fifth act (Fig. 13)—the first act courtyard,—occupying the major portion of the stage, had the advantage of being put in place during a preceding scene, besides having an "act wait" to aid in its final completion. It was followed by Hero's "Monument" (Fig. 18), a "front scene," succeeding the courtyard and preceding the terrace, that occupied the shallowest possible amount of the stage and, all being painted on one drop, could be set by merely clearing the "down stage" first entrances. The remainder of the courtyard could then be "struck"—and the *entire* last scene, the terrace (Fig. 19), put in place—behind this "front scene" drop.

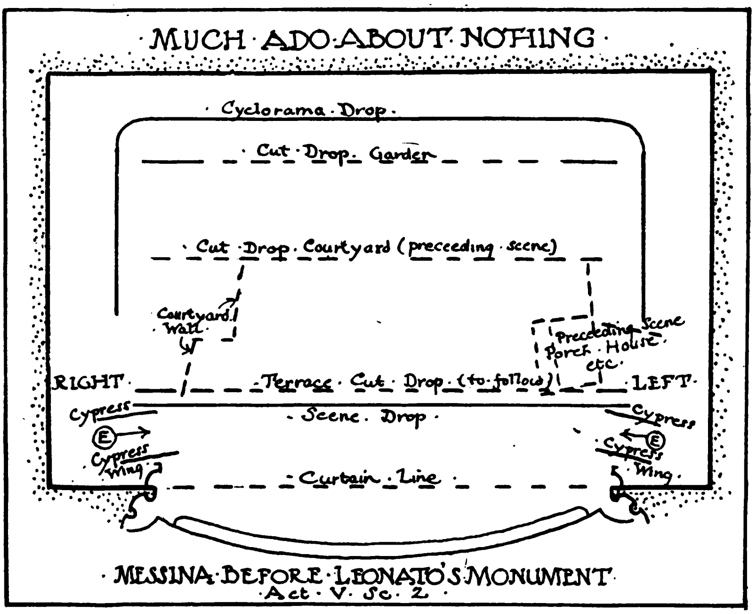


FIG. 18.

The preparation of the scenery for a Shakespearian play cannot be begun until the version to be employed is well nigh complete. Not only must the size, arrangement and succession of scenes be first definitely decided, but a very considerable amount of the "business" must also be roughed out and generally determined. The use of a large mob, as is required for the Forum scene in "Julius Cæsar," and the "Public Place in Verona" that generally opens the play of "Romeo and Juliet," at once determines that a large part of the stage will be necessary for these scenes, and so their placing and sequence be-

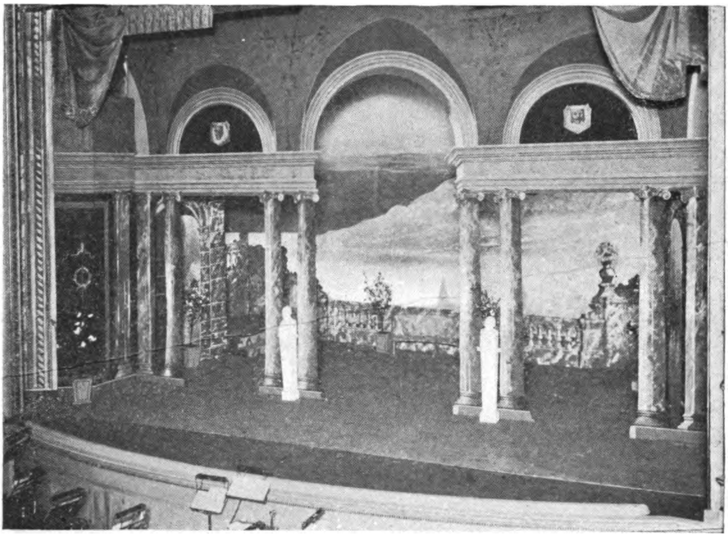


PLATE II.

comes a factor influencing the design of the several adjoining scenes as well.

The term "business," in theatrical parlance, includes every entrance, movement, action or expression; almost everything else, in fact, other than the actual spoken words and lines in the actors' parts. Business is always supposedly suggested by, or introduced to be explanatory of, the author's lines and the situations that develop from them. The actual written speeches of a play rarely exercise any direct influence, one way or the other, upon the settings; while almost every bit of "business" is

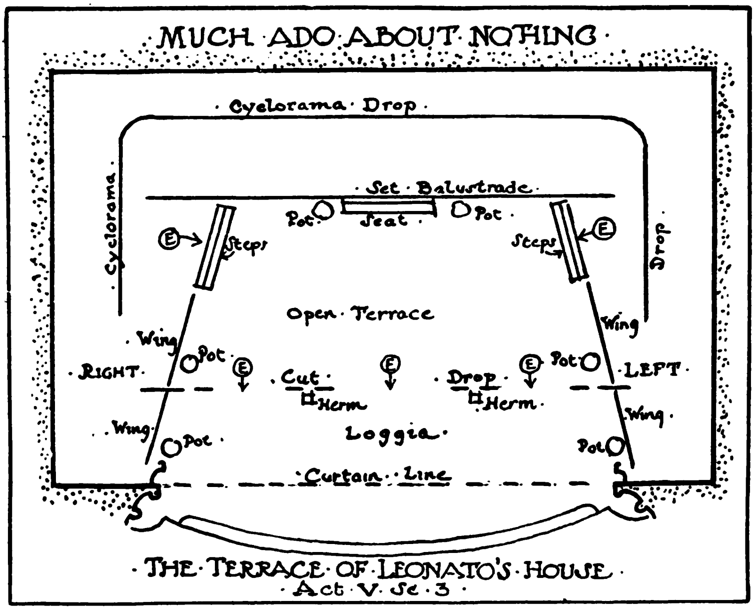


FIG. 19.

importantly dependent upon the arrangement of the stage and its scenic setting. Shakespeare's brief descriptions giving the location of each scene are always worthy of the most particular attention; but even they have no direct bearing upon the arrangement of the settings, although their suggestive and inspirational value is inestimable. The stage manager—and his "business"—determines which scenes are most important and therefore those that, in the version he has elected to use, require the use of certain greater or less areas of the stage for their proper acting and presentation.

Other than furnishing a mere background for the players —its most important function from the point of view of the audience—it is necessary for the scene to provide the necessary entrances and exits, most advantageously arranged for obtaining the dramatic effect that each actor's entrance or exit is intended to develop. An especially brilliant or pompous entrance, requiring a certain amount of preparation and anticipation, may absolutely *demand* an opening at the back and very near the centre of the stage.

The first act of "Much Ado" offers an example. A few characters are discovered upon the stage at the rise of the curtain. Later enters a messenger, announcing the coming of the troops. The household gather in the courtyard to receive them. One or two characters are outside the gate describing their near approach. A moment more and the first of the returning warriors enters through the centre gateway in the "cut drop" that enables these characters to appear at the one point on

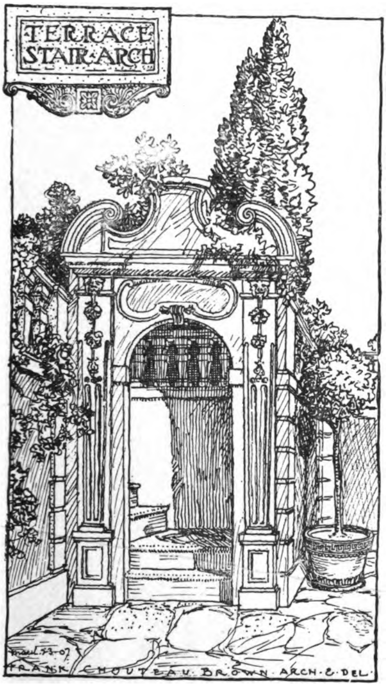


FIG. 20.

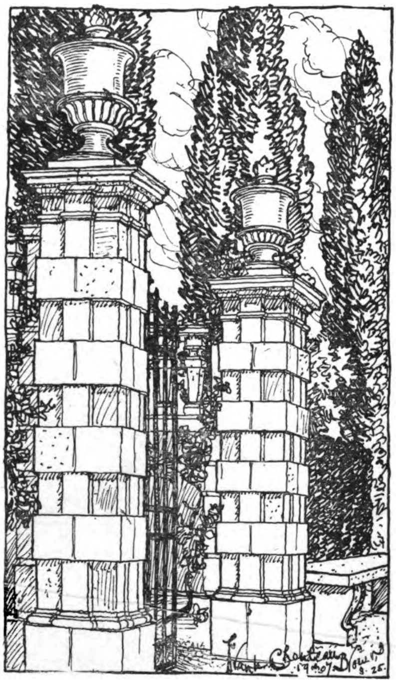


FIG. 21.

which the attention of the entire house is psychologically and physically most advantageously focused. An added seasoning to the interest was even provided in this scene by the moving spear tops, banners and ensigns of the entering nobles and their retinue, appearing over the top of the courtyard wall as they neared the centre entrance. This same scene, when used again in the last act, also provided entrances and exits as effective for the action of that part of the play. As a rule, however, it is

much easier to design a setting suited to picture the mood and arranged to fit the action of a single scene, than one required to be used again and again during the progress of the play. The varying intensity of the scenes, and their differences of mood, either render the setting inappropriate to some among them; or it is likely to appear lacking in color and characterless, and so run the risk of proving monotonous and wearisome to the auditor.

Not only did the arrangement of the back of the courtyard scene add effectiveness both to the picture and the action; but

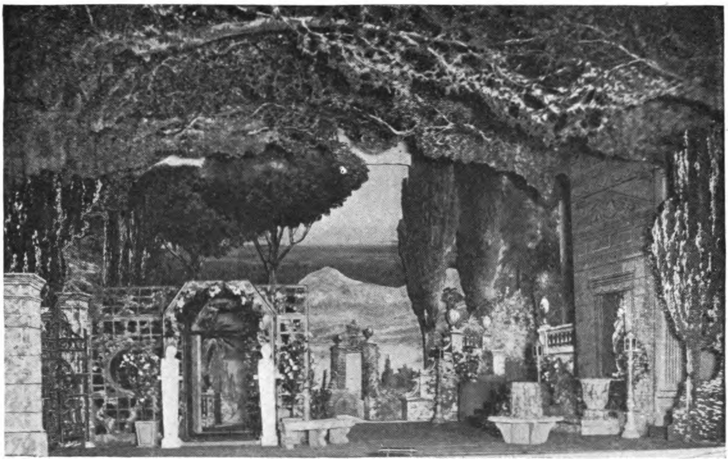


PLATE III.

it also served the purpose of hiding the flight of seven or eight steps, with the heavy buttresses and platforms (Fig. 4), that formed the most important entrance for the succeeding scene. This made it possible to put in place this cumbersome and heavy portion of the second act, all taking time and care to properly set, before the curtain rose upon the opening scene; so saving a considerable amount of time in changing from the first to the second set. Occurring in the left upper corner of the garden scene, the value of this entrance was increased both by the height to which it was raised above the stage and by its location; that, by referring to the photograph of the completed scene, will actually be found not far removed from the centre,

despite the fact that it was apparently placed well to the side, of the stage. It was further given quite all the psychological importance of the first act gateway by the composition of the back drop, which was such as to draw the interest to a point just at the foot of this flight of steps, and by the fact that the "lines" of the architecture (Fig. 24) at the left of the stage all converged toward this same point. Of course, it was this entrance that was used by Beatrice for her scene, at one climax of the act, beginning, "Against my will I am sent to bid you come in to dinner," and her exit immediately after, followed by Benedict.

There are, in this and every other scene, a thousand little bits of action, for which the scenery and settings have to furnish an excuse or a suggestion, or which the actor has to subordinate to the surroundings that the stage manager and scene painter provide for him. It is, of course, impossible to suggest in an article of this kind any but two or three of the most important instances, but there is one more that should be mentioned. The most difficult problem of the many provided by this second setting was to furnish the necessary machinery for the eavesdropping scenes between Beatrice and the women, and Benedict and those concerned in the conspiracy to get him to fall in love with Beatrice, without making its purpose too strongly apparent. It was necessary not only to give the conspirators a place to sit and talk, but further, an opportunity for the listener to be hidden from them while at the same time she, or he, was fully disclosed to the audience. The small semicircular seat at the corner of the arbor provided the location for the more important of the conversations by these merry conspirators of Cupid, the listeners being either inside the arbor at the down stage entrance; or at the opening just at the other end of the seat; or beyond the arbor, above and back of the gossiping meddlers.

In designing a stage setting, it is necessary to first secure all the data as to the location, place and period of the play; then all the stage manager's requirements for his business, entrances and exits. These facts once determined, the designer can then compose the picture in his own mind. The difficulties he will next experience are those occasioned by adjusting his

picture, with its different painted "planes," to those actual planes supplied by his arrangement of wings and drops, and the different other constructive members on which his scene is necessarily based. Drops are about 40 feet wide by 30 feet high. Wings are ordinarily 6 feet wide and 20 feet high. At the extreme they ought not to vary over a couple of feet either way from these standard dimensions: and "wings" and "drops"

FIG. 22.

("cut" or "solid") are the principal mechaniæ upon which the designer has to depend for constructing his picture and projecting its effect across the footlights.

After making a sketch for the entire picture as it will appear to the audience (Figs. 22 and 23), each individual piece of scenery may then be studied out. Not only the drawing of the scene to be painted upon it, but also the actual outlines and

construction of each piece of scenery upon which these outlines are to be painted, must be determined (Fig 24). It is in this process of working-out that the "model" is developed.

The "scene model" is customarily made at the scale of half an inch to the foot and will show, on stiff cardboard, in miniature, the exact size and dimension of each piece of scenery; while drawn or painted upon its face is an exact representa-

FIG. 23

tion of the picture that is to be there executed at the larger scale by the scenic artist. These models, when assembled together upon a miniature stage, should give, both in effect and detail, the appearance that the large scene will have when completed. When accepted by the stage manager, they are turned over to the carpenter, who then marks upon the back of each piece the frame construction necessary to support and hold the

canvas into the shape required (Fig. 25). When mouldings or ornaments projecting above or at the sides of the wings are called for, he has to build out these places with "profile" (thin strips of wood covered with canvas, or "scrim," glued upon them, so as to prevent their splitting with the grain) held in place by a properly braced light wooden framework.

The painter generally marks off the surface of the model in squares of a scaled foot or two foot size (depending upon the amount of detail in the design) and draws corresponding squares upon his canvas, numbering them from the centre out to each edge—in the case of a drop—and from the bottom to the 20 foot of the height determined by his wings—in the case of both wings and drops. It is then a comparatively easy matter to enlarge the design and sketch it out with soft charcoal upon the canvas, which has already been primed and sized with glue and a body color that is suggested by the general color tone

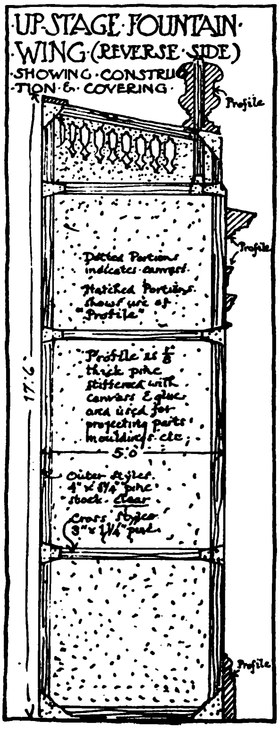


FIG. 25.

of the scene. The distemper colors used in painting scenery are dry powdered pigments that are mixed with glue and hot water, and have such body and consistency that they entirely cover up any color over which they are brushed. It is, therefore, possible to paint light tones over dark as easily as to paint dark tones over light, and by this means the painter slowly piles up one color over another, settling first his big backgrounds and adding last his more minute and finishing details, until each piece of canvas is finally completed and lowered to the stage below. After the painter has finished his painting, he has marked in red paint the outlines to be "cut"; as the carpenters have still to saw the profile or cut the canvas out to the edges of the mouldings marked before the scenery is ready to be put in place.

Scenic perspective is not so especial and particular a problem as is generally believed. So long as certain simple and

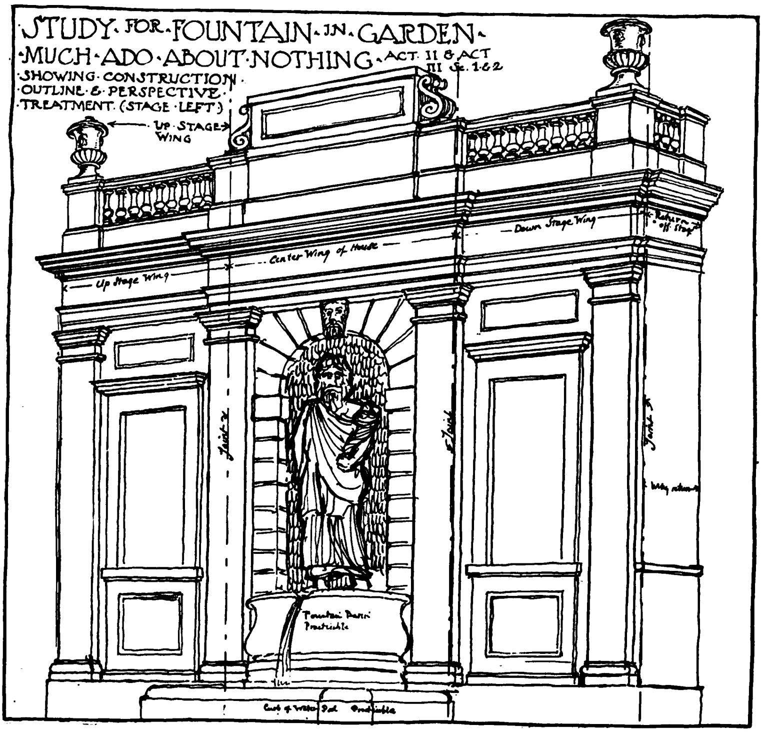


FIG. 24.

self-evident rules are borne in mind, it need not present any great difficulty to the designer. It is, of course, necessary that every portion of the stage to be occupied by the actors be not thrown so far away in painted perspective as to cause the doorways or windows to be "out of scale" with the unit of measurement offered by their bodies' height. There are various ways of avoiding this direct contrast. The actors may be kept to the "down stage" portion of the scene, or children of different sizes and heights may be dressed up in the clothes of full grown persons, and so placed at the back of the stage as to illusively in-

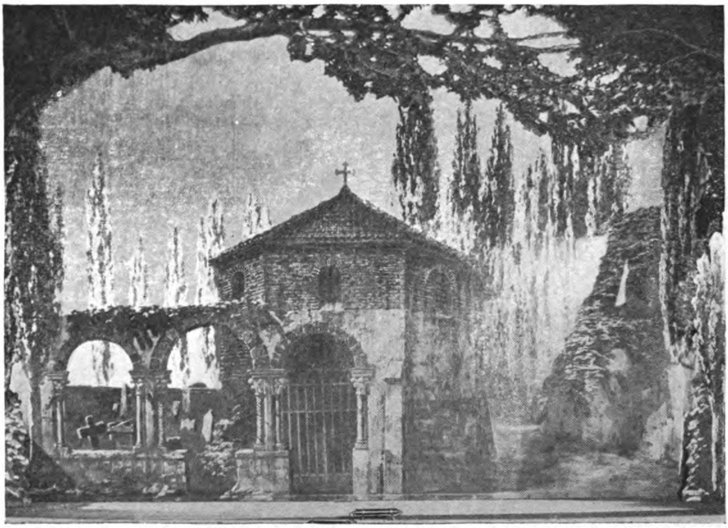


PLATE IV.

crease its size and the depth of the picture. Again, in raising the horizon line for the effect of the distance to be painted on the back drop, it is well to get the desired effect with the least possible increase in the height of the line of vision over the customary six feet of real life. The higher it is raised, the more difficulty will be experienced in correcting the convergence of the lines below the horizon; which ought, of course, to slope *up* toward the vanishing point, whereas, as a matter of fact, they have actually to be parallel with the horizon line from that point down to the floor of the stage. There exist various obvious means of avoiding this defect, too, although

expensive and therefore but seldom actually employed. For one—the floor of the stage may be gradually raised toward the back scene so as to allow these lines to *apparently* converge. Unless the horizon line is raised considerably, however (and the higher it is raised the more expensive, slow and troublesome is this process of building up the stage to meet it), it is hardly essential to so cheat the eye of the spectator, as actually he but rarely notices a defect that is so obviously a result of actual conditions that it does not at all appeal to his consciousness as being questionable.

At the rise of the curtain upon any new scene—especially if none of the personages of the play are on the stage ("discovered" is the theatrical term) when it goes up—the audience are for a few moments acutely conscious to, and assimilative of, the "picture" first disclosed. This fact is recognized and employed to the extent that a scene is frequently lighted at the opening too dimly for the audience to obtain the full effect from the acting, solely in order to get the utmost result possible from the appeal that the picture—under the most favorable conditions—may make to their imaginations. This important moment once passed, the lights are gradually increased, or changed onto the tones giving the most light, such as amber, so as to next obtain the full results from the acting; and unless this transposition is very clumsily done, it may be effected without the audience becoming at all conscious of the change.

In the stage picture certain parts are always of more importance than others. Provided that the central part—the focal point—of the stage picture is the more carefully composed and painted; the sides of the stage and the borders overhead may often be slighted in execution without injuring the scene. This is invariably—and most fortunately—true of the upper part of the picture; where the "borders," or painted stretches of canvas hanging across and enclosing the scene overhead, are perhaps the most annoying and unsatisfactory among the accepted scenic conventions of the modern theatre.

If painted as the beamed ceiling of an interior set, they may—in certain limited designs—give some effect of illusion. When "cut foliage borders" are used with an exterior scene (as in the courtyard and garden sets) they are partially satisfactory; but when the canvas is painted as a plain blue sky (as

shown at the very back of the garden scene), no prose could be more halting, nothing so absolutely false and unconvincing. By hanging close to mountain and tree tops, the border-ends or "tabs" destroy any openness of effect that might otherwise be possibly obtained, and it is certainly advisable to avoid these undesirable—and even absurd—contrasts whenever practicable. One way by which sky borders were dispensed with is shown in the photograph of the last scene of "Much Ado," a scene that has already been previously described.

Ordinarily, during the progress of the action, the audience is conscious only of that portion of the scene that forms the background to the central portion of the stage, where the actors customarily move back and forth; in other words, the back drop or wall of the scene. When very important and long continued entrances or scenes are played at the extreme sides of the stage, then the attention of the audience is, of course, more directed toward the "background" that is there provided for the actors. And in that one word lies perhaps the whole secret.

After all, scenery and settings, important as they may be at certain moments of the evening, have only one excuse for being,—and that is to provide a "background" for the action of the play, and for those actors concerned in its presentation. If the settings become so over-important and clamorous as to make themselves felt for more than this,—they are as much an inevitable failure as if they did not come up to the simplest essentials of the requirement! At one extreme,—or the other, they may be accounted failures; but if included anywhere within the wide range contained between these two terminal points, they may win the high praise of being considered more or less perfectly "adequate." It is, as usual, in the attaining of the perfect mean that the greatest success is always to be secured, and therein are contained all the real difficulties of the problem!

SUPERHEATED STEAM FOR STEAM TURBINES.

BY J. A. MOYER, '99.

A voluminous writer once said that he could easily write two large volumes of what we did not know about the laws of thermodynamics. Of superheated steam this is especially true. In a few pages I shall discuss some of the most important properties of superheated steam, with which the modern steam engineer must deal; and, at the same time, I shall insert some results and laws, derived from experience, which, I believe, have not been published before.

The peculiar circumstance that water in the liquid state, can exist, indefinitely, in the presence of superheated steam, makes conclusions from experimental data and calculations often difficult. Because of this fact and the difficulty of measuring, with accuracy, the temperatures of highly heated steam, there is some reason for the indefinite state of our knowledge of the properties of steam heated above the temperature of saturation. The effect of superheat on the economy of steam turbines and steam engines can, doubtless, be obtained with a fair degree of accuracy, by taking only the ordinary precautions for a carefully conducted engine trial. When steam of high superheat is used, the analysis of the tests obtained, is, necessarily, a matter for more or less speculation. Before burdening this article with necessary calculations and thermodynamic equations, some actual results with steam turbines, obtained under actual practical conditions, will be considered.

Effect of Superheated Steam on Economy.

A gain in steam economy results from the use of superheated steam in either steam turbines or reciprocating engines. There is much discussion, however, whether the use of superheated steam is actually economical from a purely commercial view point. The merits of the points raised in this discussion will not be taken up here. It is sufficient to say that the use of a moderate degree of superheat is now very common, and leads to economy of steam consumption in all commercial

steam motors. The saving is usually considered to be about 8 to 10 per cent. for 100° F. of superheat. The water-rates in Figs. 1-3 show approximately this effect in steam consumption. Fig. 1 shows the actual steam consumption of a 5,000 kw. Curtis turbine from tests made by Sargent & Lundy for the Commonwealth Electric Co., Chicago; and Fig. 2 for a 400 kw. Westinghouse-Parsons turbine tested by Dean & Main. Fig. 3 shows *theoretical* curves of water rates for, approximately, the same pressure limits as for Figs. 1 and 2. In this figure the line marked A represents the theoretical water rates, or steam consumption, for superheated steam calculated from the energy available from the adiabatic expansion of a pound of steam, using the "ancient" value of .48 for C_p, the specific heat at constant pressure. The curved line B is calculated from more accurate values of the specific heat, taking the author's values shown in Fig. 5 (curve A for 165 lbs. abs. pressure). The curve marked B in Fig. 3, it will be observed, has a very slight curvature and gives considerably lower values for water rates than A. Through the intersection of curve B with the axis of ordinates, a straight line C is drawn in the figure to show the curvature of B. The *actual* theoretical curve of steam consumption is practically a straight line to about 100° F. superheat* and then it begins to follow a slight curve. This same sort of curvature is observed also of curves made from tests for actual steam consumption, showing the expected agreement of these theoretical curves with practical conditions.

The economy of steam due to superheat is shown on a percentage basis in the curves in Fig. 4. These curves represent by percentages the same conditions and results as Figs. 1, 2 and 3 combined, so that a more rational comparison can be made, than by mere inspection of curves of water rates.‡ Curves A and B are *typical* of the two kinds of turbines they represent, independent of the *size* or *make*. In other words a comparison of curves A, B, and C shows how the reaction type is limited in the use of superheated steam in two ways: First, for low superheats, the total efficiency is not good compared with the ideal;

*Observe that to this point the values of Cp in Fig. 5 are rapidly decreasing, and beyond, for higher values of superheat, become nearly constant.

‡The development of this percentage method of comparing water rates of steam turbines is due largely to C. P. Crissey.

and, second, the highest degrees of superheat are impracticable because of the limited endurance of materials, suitable for blades. In this type the steam comes into contact with the turbine blades at its highest temperature. On the other hand, in the "impulse" turbine the steam is first expanded in a nozzle

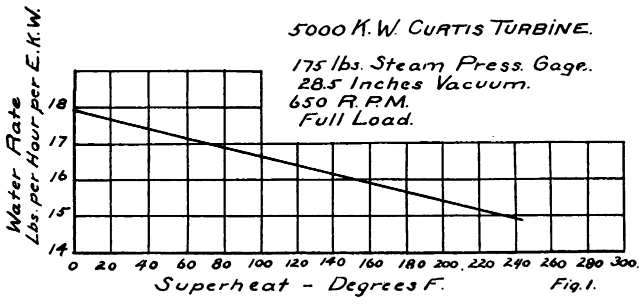


FIG. 1.

so that its temperature is very much reduced before reaching the blades. The reasons for the excellent results with the *reaction* turbine with from 150 to 200° F. superheat are therefore obvious.

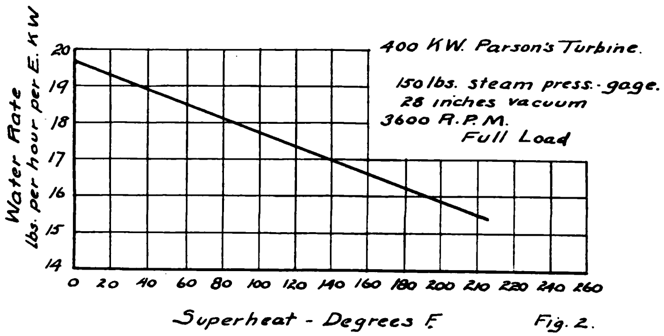
The gain in the steam economy of a turbine from the use of superheated steam seems to be due, in part, to two separate influences:

(1) Economy of the energy in the steam.

(2) Superior mechanical operation.

The superior energy efficiency has been already shown; but the effect on mechanical operation of a turbine is not always easily explained. Superior heat efficiency should give a saving of not more than 7.5 per cent. per 100° F. as shown by curve C (Fig. 4); so that heat efficiency, alone, cannot make the saving of 10 per cent., which is observed, for example, from curve A. There is, therefore, probably an improvement of 2.5 per cent. in mechanical efficiency of this turbine for an increase of 100° F. in superheat. The turbine represented by curve B approaches more nearly the theoretical. When, therefore, superheated steam is used, the percentage reduction in steam consumption corresponds very nearly with the theoretical. In other words, the *actual* heat effi-

ciency of this type will remain nearly constant from low to high superheats. To bring about this result, the two principal losses in the turbine varying with the superheat are apparently neutralized in their combined effect. These losses are (1) the fluid friction of wheels and blades, and (2) leakage between the stages of the turbine. We know that the friction of wheels revolving in superheated steam is much less than in saturated steam. Wheel and blade friction is reduced with an increase of superheat, in proportion to the density of the steam. Fig. 6 shows the *percentage* reduction of the rotation loss in superheated steam. Usually the leakage of steam increases with an increase of superheat; so that the two losses may com-



WATER RATE OF 400 KW. WESTINGHOUSE-PARSONS TURBINE

FIG. 2.

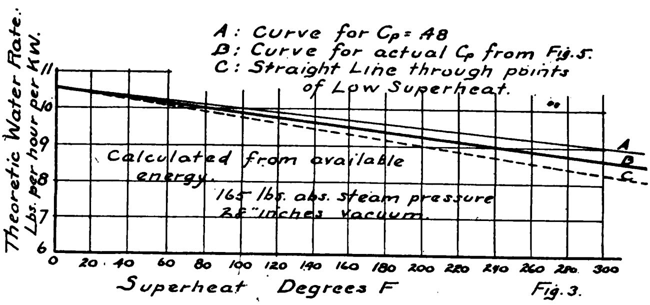
bine to nearly neutralize each other, as we observe sometimes in actual tests.

The best design of a steam turbine to use highly superheated steam is probably a combined impulse and reaction type. The impulse principle for the first stage to allow the use of the highest degree of superheat, and the reaction form, because of the greater improvement in economy with high temperatures, for the several stages after the first. For the best results, of course, the pressure drop in the first stage should be large compared with that in the other stages.

Specific Heat of Superheated Steam.

Numerous sets of data have been published from time to time, for the specific heat of superheated steam; but no two

investigators seem to agree. Some of the most recent results published are as much at variance as any. In 1862 Regnault* made the determination for steam at *atmospheric* pressure and obtained the value of .48 for the specific heat at constant pressure (C_p). From that time till to-day others have published data with only the result that no two experimenters could agree on actual values. In 1894 Lorenz† published some extraordinary values. His experiments were made at the request of the *Verein deutscher Ingenieure.* As the result of some very careful tests, he arrived at the very important conclusions that *the specific heat at constant pressure increased directly with the pressure, and decreased with an increase of temperature.* To-



THEORETICAL WATER RATES CALCULATED FOR VALUES OF C_p FROM CURVE FOR 165 lbs (Fig 5) AND REGNAULT'S CONSTANT VALUE .48.

FIG. 3.

day practically all physicists and engineers have accepted these broad conclusions; but, in most cases, there has been no reasonable agreement with the values obtained from Lorenz's classic experiments. It is probable that these experiments by Lorenz were made with as much care as any other determinations. Later experimenters were probably more concerned about the details of elaborate apparatus‡ than the reliability of values.

Considering the difficulties in the way of a *direct* determination of specific heat it seems probable that consistent results can be obtained only by indirect methods. The values for the

**Men. de l'Acad. des Sciences*, 26, p. 167.

†*Zeit. Vereines deutscher Ingenieure.* May 14, 1904, p. 700.

‡Curves recently published widely and given out as the results of ten years of experimenting in an American technical college belong to this class. *No data for the curves are published;* but unless the data for the last year are very much better than for the nine years preceding, the curves are not justified. For such important results to have any consideration the data and the methods for calculation should be available.

specific heat of superheated steam do not follow a simple law. Some other properties of superheated steam are not, however, so complex, and, furthermore, the errors of observation can be more easily eliminated. I have, therefore, attacked this problem by an indirect method: Finding first a simple law for the change of flow of superheated steam with varying degrees of superheat; then, applying this simple law to the well-known equations for the velocity and flow of dry saturated steam, satisfactory results were obtained. Only the most important steps in my calculations will be recorded here. When the data from which conclusions are taken are not given, the references will show where they can be found.

From a great mass of data on the flow of saturated and superheated steam, observed by Lewicki,* Rosenheim and others, as well as my own personal observations, I have developed the following *simple* formula for the flow of superheated steam:

$$W = W_1 (1 + aD) \qquad \text{(A)}$$

When W is the flow of dry saturated steam through an orifice or nozzle, and W_1 is the corresponding flow of superheated steam for D degrees superheat. The coefficient a is .00065 for Fahrenheit degrees and .00117 for Centigrade degrees. From reliable tests it has been found that this formula is accurate to $\frac{1}{4}$ per cent. from saturation temperature to 500 degrees F. superheat.

This law for the flow of superheated steam has, I believe, never been stated before, and gives probably more accurate results than any coefficient that has yet been found for Zeuner's law in the form of $k\sqrt{\frac{p}{v}}$ where p and v are the initial pressure and volume,† and k is a constant coefficient.

The simple form I propose in equation (A) has been checked by a long series of experiments at the Lynn Works of the Gen-

*Lewicki—*Zeit. Vereines deutscher Ingenieure*, April, 1903, p. 494-495.
Rateau—*Revue de Mecanique*, 31 Aug., 1900.
Rosenheim—*Proc. Inst. Civil Eng.* vol. 140, 1900.

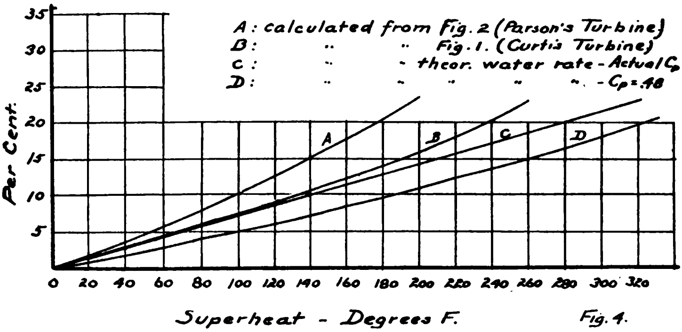
†The same form as equation (A) gives also a very convenient and satisfactory equation for values of the volume of superheated steam, for all *practical* requirements,

$$v_s = (1 + aD)^2\, v$$

where v_s and v are respectively the specific volumes of superheated and dry saturated steam, and a and D have the same values as above.

eral Electric Company and the results have been very satisfactory.

Data from which the law for the flow of superheated steam was obtained can be used to establish another remarkable property. An examination of all this data shows that the impulse force from a jet of steam is the same whether it is dry saturated or superheated, if, at least, the temperature range is not too great. Lewicki's experiments show conclusively that the impulse force for steam discharged from a given nozzle is the same for steam that is dry and saturated, or that is superheated 100° F.* General thermodynamic equations for im-



COMBINED CURVES SHOWING THE PERCENTAGE CHANGE OF STEAM CONSUMPTION WITH VARYING DEGREES OF SUPERHEAT.

FIG. 4.

pulse force, velocity, and flow can be used, however, to show the *theoretical* basis for this property. Thus, impulse force is expressed by the relations:

$$\text{Impulse force} = \text{mass} \times \text{velocity},$$

$$= \frac{W}{g} V \qquad \text{(B)}$$

where W is the flow per second, g is the acceleration of gravity, and V is the velocity; all of course, in the same linear, time, and weight units.

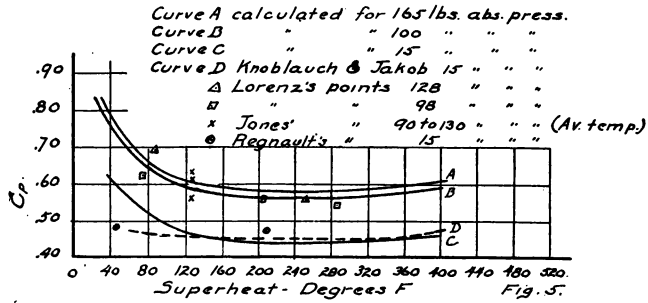
*Lewicki's experiments for impulse force do not go higher than 120° F. superheat; and the last point which does not show very good agreement was probably slightly in error. The basis for the calculations of specific heat does not lie with Lewicki's experiments, but on purely thermodynamic relations.

Zeuner's equations for velocity and flow for either dry, saturated or superheated steam are:

$$V_m = \sqrt{2\,g\,\frac{k}{k+1}\,p_1\,v_1} \tag{C}$$

$$W = \sqrt{2\,g\,\frac{k}{k+1}\left(\frac{p_m}{p_1}\right)^{\frac{2}{k}}\left(\frac{p_1}{v_1}\right)} \tag{D}$$

where V_m, A_m, and p_m, are respectively the velocity, area, and absolute pressure at the smallest cross-section; also p_1 and v_1 are the absolute pressure and specific volume of the steam before expansion, k is a constant and W is the flow per second. Now, if we calculate the impulse force from equations (C) and (D); that is, take the product of V_m and W, we obtain an equa-



COMPARISON OF VALUES FOR THE SPECIFIC HEAT OF SUPERHEATED STEAM AT CONSTANT PRESSURE

FIG. 5.

tion which is independent of the specific volume,* so that for a given range of pressure, k is the only possible variable, and the variation of k is practically nil according to all reasonable data on the subject for small differences of temperature.†

If, then, we have established that the impulse force does not vary with the degrees of superheat when the temperature change is small, we can write the relation,

$$J = J_1 \tag{E}$$

where I is the impulse force of dry saturated or superheated steam, and I_1 is the impulse force of steam at a higher temperature than for I, but for the same pressure range. In other words, remembering equation (B), we have

*I am indebted to M. Nusim for this mathematical statement of the thermodynamic relations.

†Weyrauch—*Zeitschrift Vereines deutscher Ingenieure.* Jan., 1904, p. 24.

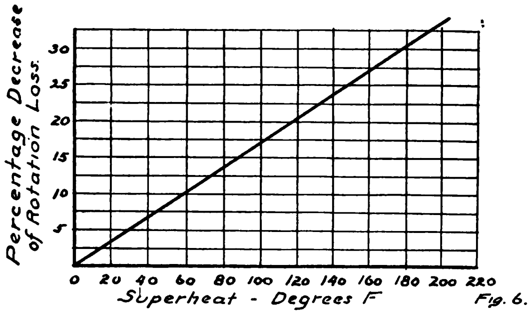
$$W \times V = W_1 \times V_1 \,*$$

In the calculations following, equations, (C) and (D) for velocity and flow were not used, but instead the simpler forms:

$$W = A\, C\, p_1^{.97}\dagger \qquad \text{(F)}$$

$$V = \sqrt{2\, g\, E} \qquad \text{(G)}$$

In these equations A is the area of the orifice or nozzle, C is a constant, p_1 is the absolute initial pressure, E is the available energy from adiabtic expansion, W and V are respectively flow and velocity as before. From these last equations we can



THE EFFECT OF SUPERHEATED STEAM ON THE ROTATION LOSS OF DISCS AND BLADES. AN AVERAGE CURVE FOR THE USUAL PRESSURES IN IMPULSE TURBINES.

FIG. 6.

express impulse force in simple terms lending themselves easily to calculations, thus,

$$I = \frac{W\, V}{g} = A\, C\, p_1^{.97} \sqrt{\frac{2\, E}{g}} \qquad \text{(H)}$$

From equation (A) we established the relation between the flow of saturated and superheated steam so that we may modify the last equation for superheat, and obtain,

$$I_1 = \frac{W_1\, V_1}{g} = \frac{A\, C\, p_1^{.97}}{1 + a\, D} \sqrt{\frac{2\, E_1}{g}} \qquad \text{(I)}$$

where E_1 is the available energy of steam at D degrees superheat. Now for small differences of temperature, as before,

$$I = I_1 \qquad \text{(E)}$$

*In all the terms that follow the symbols with the subscript 1 are intended to refer to the condition represented by I_1.

†This equation is known as Grashof's law for the flow of dry saturated steam. Cf. Grashof's "*Theoretische Maschinenlehre,*" vol. I, iii; Hütte Taschenbuch I, p. 333.

and therefore equating (H) and (I), and simplifying the result,

$$E = E_1 \div (1 + a D)^2 \tag{K}$$

where E (the available energy for dry saturated steam) is easily calculated from the equation,

$$E = \lambda_1 - \lambda_2 + T_2(\phi_2 - \phi_1) \tag{L}$$

in which λ_1 and ϕ_1 are respectively the total heat and entropy of saturated steam at the initial pressure; and λ_2, ϕ_2, and T_2 are the total heat, entropy, and absolute temperature at the final pressure after adiabatic expansion. On the other hand, the available energy of superheated steam, E_1, is given by the equation,

$$E_1 = E + C p \left(D - T_2 \log_e \frac{T_1^1}{T_1} \right) \tag{M}$$

for the case where the *final* condition of the steam after expansion is saturated. In this equation E and T_2 have the same significance as in equation (L), D is degrees of superheat, T_1^1 and T_1 are respectively the absolute temperatures of superheated steam and of saturated steam for the initial pressure, and C_p is the specific heat at constant pressure. For the other case where the final condition is superheated, a slight modification of equation (M) is necessary, involving a trial and error method of calculation. Actually an entropy-total heat diagram of very large scale was used to evaluate C_p in this case for trial values. The substitution of these values, then, in the general equation gave exact agreement.*

The curves showing the values of C_p obtained from these calculations are given in Fig. 5, for pressures of 165, 100, and 15 lbs. absolute.

Engineers in charge of new installations for power plants, can use these curves of the specific heat of superheated steam very profitably. Continually the question arises, as to how much superheat should be used to produce the best economy, as measured by pounds of coal. With the help of these curves the total heat, λ_s, in a pound of superheated steam is easily found by the formula:

$$\lambda_s = \lambda + C_p \; D. \tag{N}$$

*In every case the temperature range was taken as small as was possible with the limitations of Grashof's law; *i.e.*, the final pressure was not greater than .58 of the initial pressure. This is the only condition for which equations (C) and (D) are intended, and these equations are given to show that impulse force is independent of the specific volume, and is constant for varying superheats.

Knowing the calorific value of the coal used, and the heating efficiency of the boiler plant, the coal required per kilowatt-hour can be readily calculated. To make this plainer, a practical example will be taken for an illustration. Let us assume that the builders of a steam turbine have provided a superheat-economy curve like Fig. 1, for 165 lbs. absolute steam pressure. The heat value of a pound of the coal used is 13,000 B. T. U., the efficiency of the boiler plant is 75 per cent., and 1050 B. T. U. are required to convert one pound of feed water into dry saturated steam. Take the case, then, of 100° F. superheat, where C_p at 165 lbs. pressure is .62. The heat for converting the feed-water into superheated steam at this temperature is $1050 + 100 \times .62 = 1112$ B. T. U. From the other data given, this is .114 lb. of coal per pound of steam. The superheat-economy curve (Fig. 1) gives 16.7 lbs. of steam per kilowatt-hour at 100° F. superheat; and we calculate 1.91 lbs. of coal per kilowatt-hour. In this way the results in the following table have been calculated for a considerable range of superheat:

Condition of Steam.	Coal per kw.-hr., lbs.
Dry saturated	1.92
30° F. superheat	1.94
50° F. superheat	1.93
100° F. superheat	1.91
200° F. superheat	1.85
300° F. superheat	1.81

For some reciprocating steam engines with a superheat-economy curve of the "concave-upward" form,* which is very common, somewhat different results would be expected.

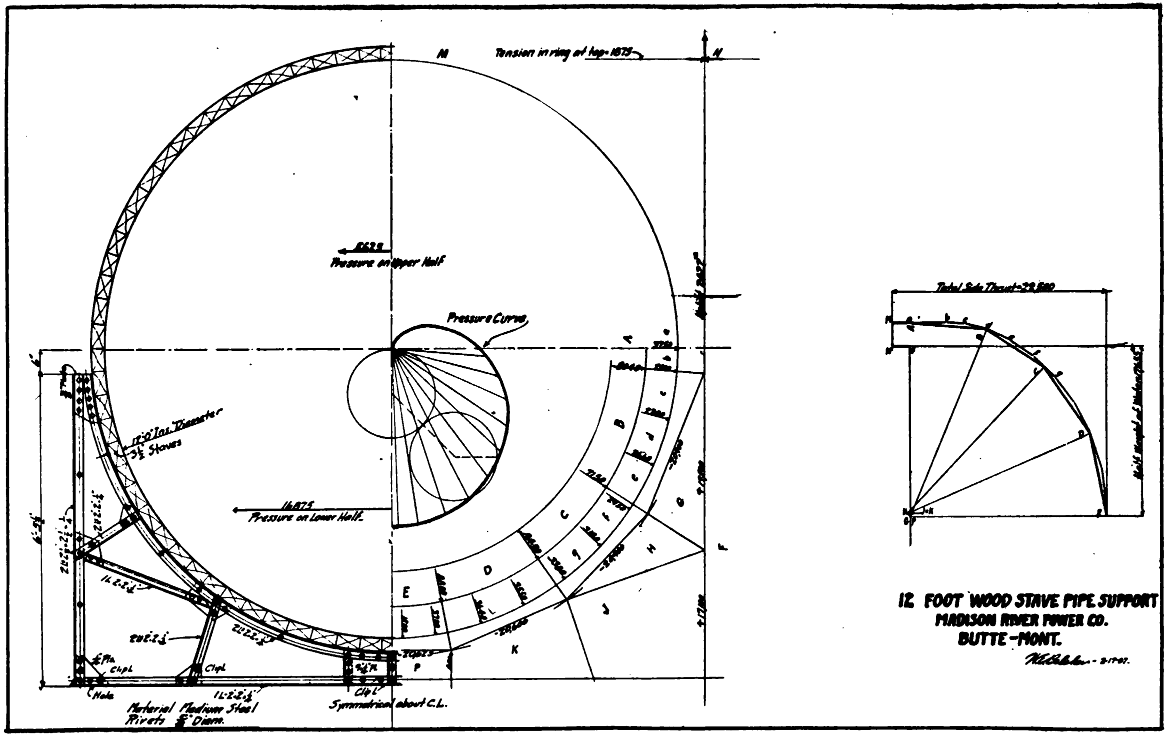
WOOD STAVE PIPE LINE. MADISON RIVER POWER COMPANY.

BY W. E. BELCHER.†

The Madison River Power Co. operates a power plant in Western Montana, supplying electric power to the city of Butte and vicinity. A heavy crib-work dam is built across the Madison River at Ennis, Montana, from which the water is led through a wood stave pipe along a grade at the side of the canyon, a distance of 7,635 feet to the power house. The original pipe line is 10 ft. in diameter, carrying water at a maxi-

*Proc. Am. Soc. Mech. Engrs., June, 1907.

†43 Exchange Place, New York.



12 FOOT WOOD STAVE PIPE SUPPORT
MADISON RIVER POWER CO.
BUTTE-MONT.

mum velocity of 8 ft. per second. The total fall from the level of the water above the dam to the tail race is 123 feet, of which 115 ft. are utilized by the power house. Using this loss of head of 8 ft., the volume of water available at the power house, figured from Kutter's formula, where N. equals .13, gives a discharge of 506 cubic feet per second, or an average velocity of about 6 $\frac{1}{2}$ feet per second. After the plant was put in operation, Mr. M. Hebgen, the General Superintendent of the Company, made a series of tests by the Pitot tube method, and found that the actual quantity of water delivered under the above conditions was 580 cubic feet per second, or 15 per cent. in excess of that shown by the formula. This amount corresponds closely with the formula if N. be used as .12. The grade upon which the first pen-stock was built was made of sufficient width for a second pipe to be laid parallel with it, and it was recently found necessary to provide a 12-ft. pen-stock for the additional water supply desired. Using Kutter's formula with N. equal to .12, this pen-stock is capable of delivering about 950 cubic feet per second.

One of the interesting problems in connection with the design of this exceptionally large wood stave pipe was that of supporting its weight and of strengthening it against collapse during filling and emptying. At these times the water exerts no upward pressure against the top of the pipe, and there is almost no tension in the circumferential bands. To assist in maintaining the circular cross section the 10-ft. pipe is supported at intervals of four feet by a steel frame, which bears continuously against the lower half of the circumference of the pipe. This general scheme has proven satisfactory, and was adopted for the new line. It was decided to support the pipe at intervals of 5 ft., the staves being made four inches thick to carry the weight between these points, and to get sufficient arch action to prevent the top of the empty pipe from collapsing. These staves were of Oregon fir, 12 inches wide and from 12 to 24 feet long.

The pipe is banded with $\frac{7}{8}$ inch diameter rods, with adjusting nuts, spaced 12 inches apart at the upper end, where the head will be 20 feet, and 7 inches apart at the lower end, where the head will be 30 feet. The accompanying diagram shows the design for the steel frame and the stresses which were used in working it out. Taking the pipe as simply full of water with no pressure at the top, the radial pressure on any part of the inside of the pipe is proportional to its vertical distance be-

low the top. Working out this pressure on the right half of the pipe, and plotting from the centre of the pipe, gave the epecycloidal curve shown. It was found that this curve is that generated by a point in the circumference of a circle of diameter equal to the pressure at the centre of the pipe, revolved on a similar circle drawn with the centre of the pipe as it is top point. To use this curve in finding the pressure per square foot at any point on the inside of the pipe, draw a radius to the point in question and scale on this radius the distance from the centre to its intersection with the curve. The lateral pressure on the upper half of the pipe is 5,625 pounds, 1-3 of which was considered as taken by the top band and 2-3 as concentrated at the top of the steel frame. The total lateral pressure is 22,500. Subtract the small amount of stress allowed in the top band, and the horizontal stress on the frame at the bottom of the pipe is found to be 20,625.

The forces a b, b c, etc., given around the circumference at 1 ft. spacing, represent the total pressure for five lineal feet, considered as acting radially against the pipe. The force diagram is represented by the lines a b, c d, etc., and the working lines of the frame are shown under the right side of the pipe. Resultants of the smaller forces were found that can be considered as acting at the intersection points of the frame. These are the forces A. B., B. C., etc. The force polygon is the line A. B. C. D. E. P. J. F. N. M. A. This shows very little stress on the web members, and a stress on the ring that is very nearly uniform between 20,000 and 21,000, which was the object desired in designing the outline of the frame. The maximum stress on the web numbers comes when the pipe is half full, or when the supports are not at the same level, and these sections were made larger than the stresses shown would require in order to accommodate such irregular conditions.

The ring angles are 2-2 x 2 x 1 $\frac{1}{4}$, with a gross area of 1.88 square inches, or a net area of 1.50, which at 15,000 pounds per square inch tension, are good for 22,500 pounds. The side posts are designed with 2-2 $\frac{1}{2}$ x 2 $\frac{1}{2}$ x $\frac{1}{4}$ angles, which are good for 22,000 pounds in compression, using the formula P equals

$$\frac{15{,}000}{1+\frac{l^2}{13{,}500\, v^2}}$$ where L equals 6 ft.

The ring as thus designed weighs about 420 pounds, or 84 pounds per linear foot, showing a slight saving in weight over the old ten-ft. frame.

THE JAMAICAN LABORER.

BY CHARLES MAYO HARRINGTON, '05.

In view of the constantly increasing number of tourists who visit Jamaica, it is rather remarkable how little the average person knows about the people and customs of that beautiful tropical island. To a northern contractor assuming any large undertaking in the West Indies there is presented an unusual condition of labor and supply of materials that can only be met by actual experience on the ground, for until he is actually there and at work he cannot begin to understand the peculiarities of the native workmen upon whom he must depend, nor realize that he is fifteen hundred miles from his base of supplies. If anything is suddenly needed, like a new part to replace a broken one in any of his machinery he cannot step to the telephone and order it. At least three weeks must elapse before the new gear or wheel can arrive from the United States, and often it will be a month before it comes. Sometimes a message by cable will bring it sooner, but not always.

When, in May, 1904, the Aberthaw Construction Co. of Boston sent a number of its men to Port Antonio, Jamaica, to build a reinforced concrete winter residence with stables, gate lodge and other buildings for Mr. Alfred Mitchell of New London, Conn., not one of us knew what was before us. Beside the Superintendent, Edward F. Clasby, the engineer, Prof. A. W. French, of the Worcester Polytechnic Institute, and the office force, the party consisted of several carpenters, a millwright to care for the machinery, and a good concrete foreman. Both the superintendent and engineer were accompanied by their families.

The Mitchell property, known as "The Folly," for every property in Jamaica has a name, is an ideal location, on a long point of land with the harbor on one side and the open sea on the other, and is two miles from the town and wharves.

After building shanty office, tool room, cement shed and a shack for the men, we began hiring natives for excavation and carpenter work, and right there began our education in the peculiarities of the Jamaica negro, and also the strain on the patience of the entire force, fresh from the hustle and drive of northern work.

The Jamaican negro is the best natured, happy-go-lucky fellow on earth, with the mental caliber of a child, and we soon found they must be handled like children. Patience and kind dealing accomplish a lot with them, but they will not be driven. Unsatisfactory as they are as workmen, they are much better than our own southern negroes in many ways, for a white woman is perfectly safe in Jamaica.

Every one carries a machette, which he uses for any purpose, from digging to splitting a board, or opening a cocoanut, and after the building was staked out some of the laborers began to dig with their machettes, unmindful of the plentiful supply of shovels. But they soon stopped that. All were barefooted, and it made one shudder a little to see them put a bare foot on the top of a shovel to drive it into the earth, or to imagine what might happen if a pick slipped. Our fears were groundless, for the soles of their feet are so tough that when one of them stepped in some hot coals, raked out from under the engine boiler, he burned the top of his foot, but not the bottom.

Our stone crusher and concrete mixer were the first ever used in the island. All broken stone used on the roads or in concrete work, of which there are many good examples, is broken by hand, generally by women, sitting astride their stone piles, pounding away with hammers at stones held between their knees. The common price for this work is three pence or six cents a barrel.

All the stone used in our work was quarried out of a coral reef on the property and brought to the crusher on a gravity railroad. The stone car was in charge of a big, burly black boy, who took great pride in his "special train." He wore in the front of his cap a large piece of tin, on which he painted C. E. P. No. 9, which he said meant " Conductor, engineer and professor of train No. 9." When his car started down the slope he would talk to it, and as it gained momentum he would sing at the top of his voice. We always knew when a car was coming.

One day a piece of wire became entangled in a wheelbarrow wheel, so that it clicked against the spokes. This pleased them so much that more than half the wheelbarrow gang equipped their barrows with similar wires. We did not object as the faster the barrow was moved the faster the wire clicked,

and a decided increase of speed was the result. When the gang was busy it was easy to tell from the office just how fast they were working.

The educated negroes speak very correct English, but the laboring and peasant classes have a dialect that is hard to understand. We found it was necessary to learn some of it to make them understand what we wanted. If one was told to bring a long rope or dig a hole three feet deep he would look puzzled, but a "tall rope" or a hole three feet "tall" he understood perfectly.

The first pay day was an exciting one. It had been showery weather and rain time had been deducted from the pay. Men and women both rebelled, shouting and arguing all together, and refused to work any more unless they were paid. We had not been there long enough to know their temper and it looked to us like a riot. But a few words from the superintendent quieted them, and his promise that they would all get what was due them sent them back to work. From that time they trusted him, and his endless patience soon won their respect and affection. In a very short time he had a very efficient gang on the mixer, a few more intelligent ones were running the machinery, and everything going smoothly.

The ones that needed the most watching were the carpenters. The so-called skilled laborer is a little higher mental grade than the common laborer, but not enough higher to meet the requirements of his trade. If told to get out five boards six feet and four inches long he is more than likely to get six boards four feet and five inches "tall." The sense of a right angle seems entirely missing. The centering for concrete had to be watched all the time or it never would have been square. In measuring between two lines or across a plank they would lay the rule at any angle except a 90° and make a wrong measurement. When one of them was shown he had made a form a half inch too narrow, he laid his rule across at a slightly oblique angle to prove he was right. Prof. French, using the engineer's level, gave a point on the side of stake that was driven into the ground in a slanting position and told a carpenter to make a *level* mark across the stake. The latter promptly placed a steel square against the sloping side of the stake and drew his line through the point. It was perpendicular to the side of the

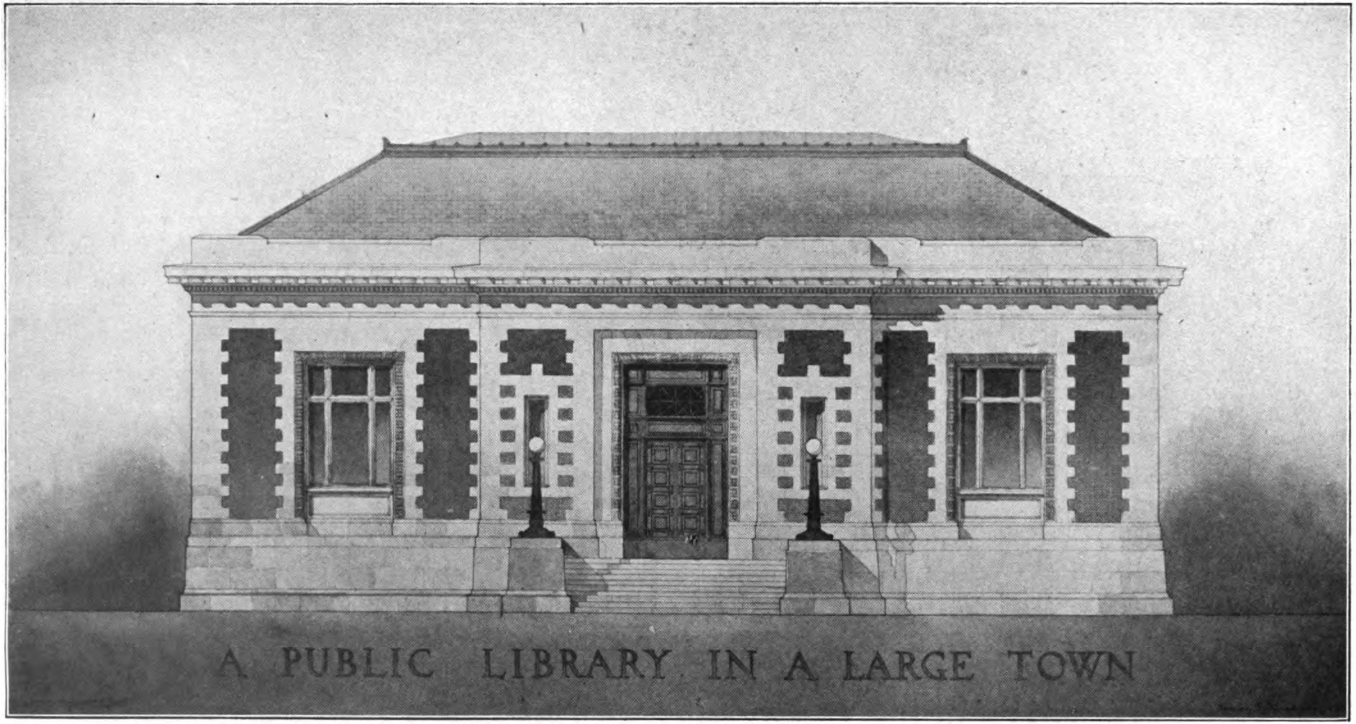
stake, but certainly not level, and he could not understand why not.

These are a few of the difficulties of tropical labor. But there is really much to be said in favor of the Jamaican. Many articles have been printed about the worthless quality of Jamaican laborers on the Panama Canal. It is true that the high wages offered attracted many men who could not have found any steady work at home. Many who could not drive a nail without bending it, bought a saw and hammer and went to Panama as carpenters. It is true that many others capable of doing plenty of work were not properly managed. It was our experience that when paid by the day they will only do just so much, but if paid by the quantity or the task they will do twice as much in a day and the total cost is much less.

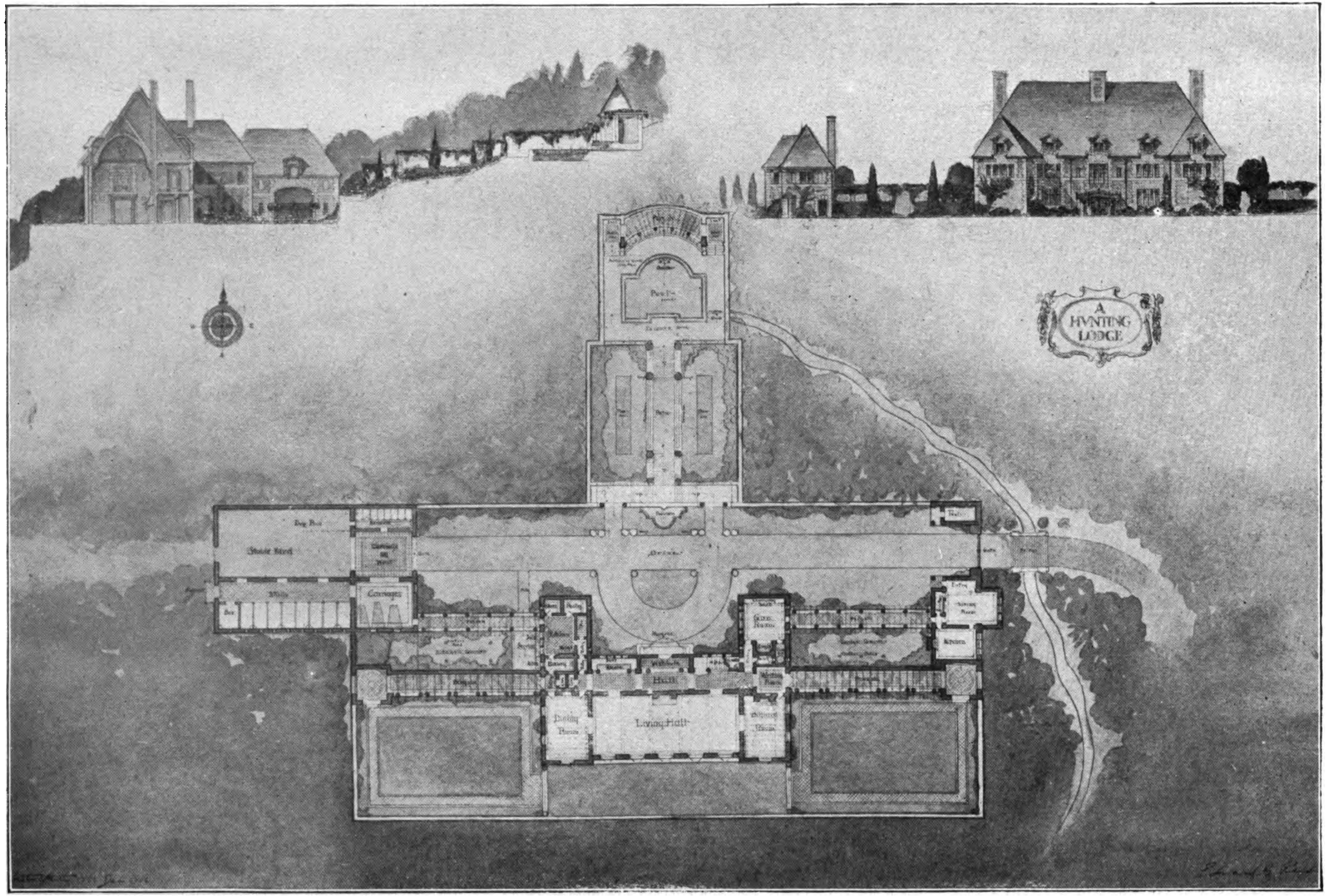
The Jamaican, almost invariably, is broad shouldered and deep chested, with slender, lean flanks, and that type of laborer is capable of doing a lot of work. But he will not be driven. Swearing at him only makes him sullen. He can lay back in the traces as stubbornly as one of his own mules. Any attempt to handle him as foremen use Italian laborers will bring a polite but firm "Excuse me, sah, but Ise a British objeck', an' us ain't like to be cuss-cuss."

In building the railroads in Jamaica and in Equador they gave good results. They were handled by men who understood them. They trust an American or English employer. In spite of the former trouble with them, the canal must depend largely upon them for its labor. It would be money well spent if the Canal Commission would send its foremen to Jamaica and let them see how the contractors, the Department of Public Works and the planters handle the men, how they arrange work, and how they pay for it. Of the skilled labor not much can be said. It is poor at its best. There are some exceptions, but they are few. But from common labor much more can be obtained than has been.

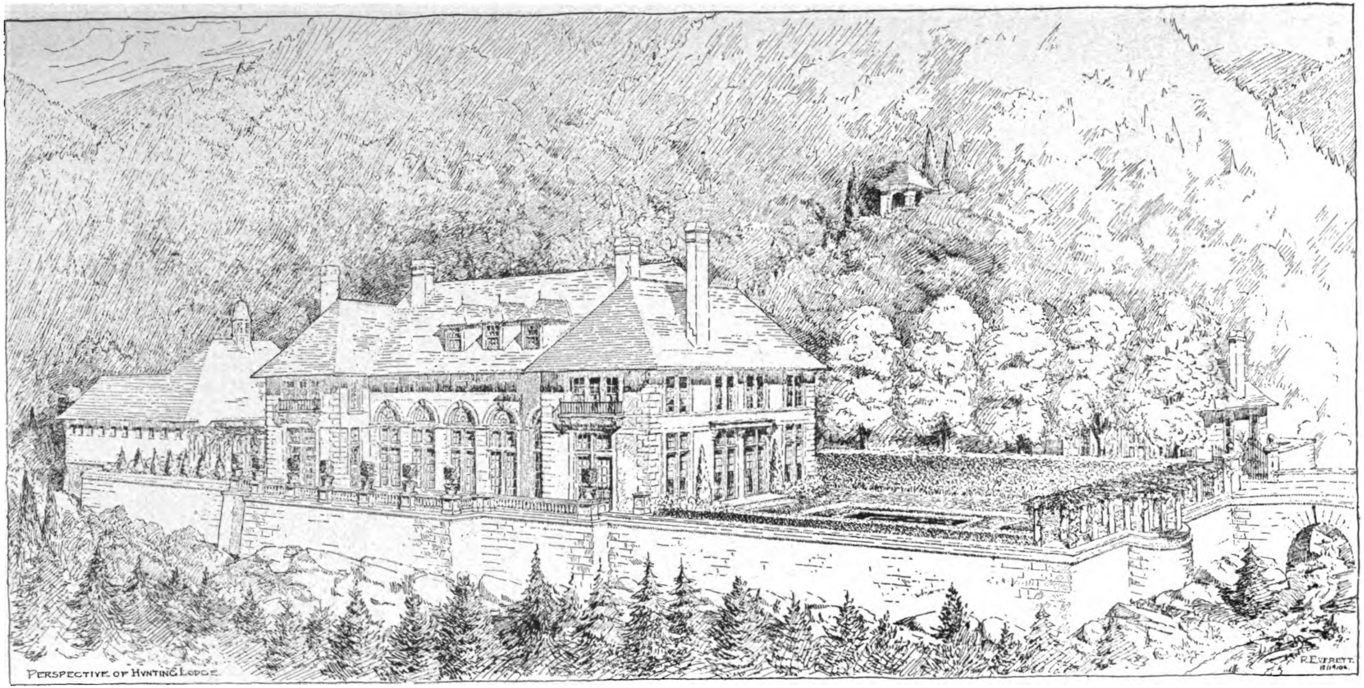
Patience and firmness in handling, arrangement of work on a task basis, and promptness in payment of wages, will prove that there is at least a grain of truth in the old Jamaican proverb, "A Jamaican nigger and an American boss can dig down the world."



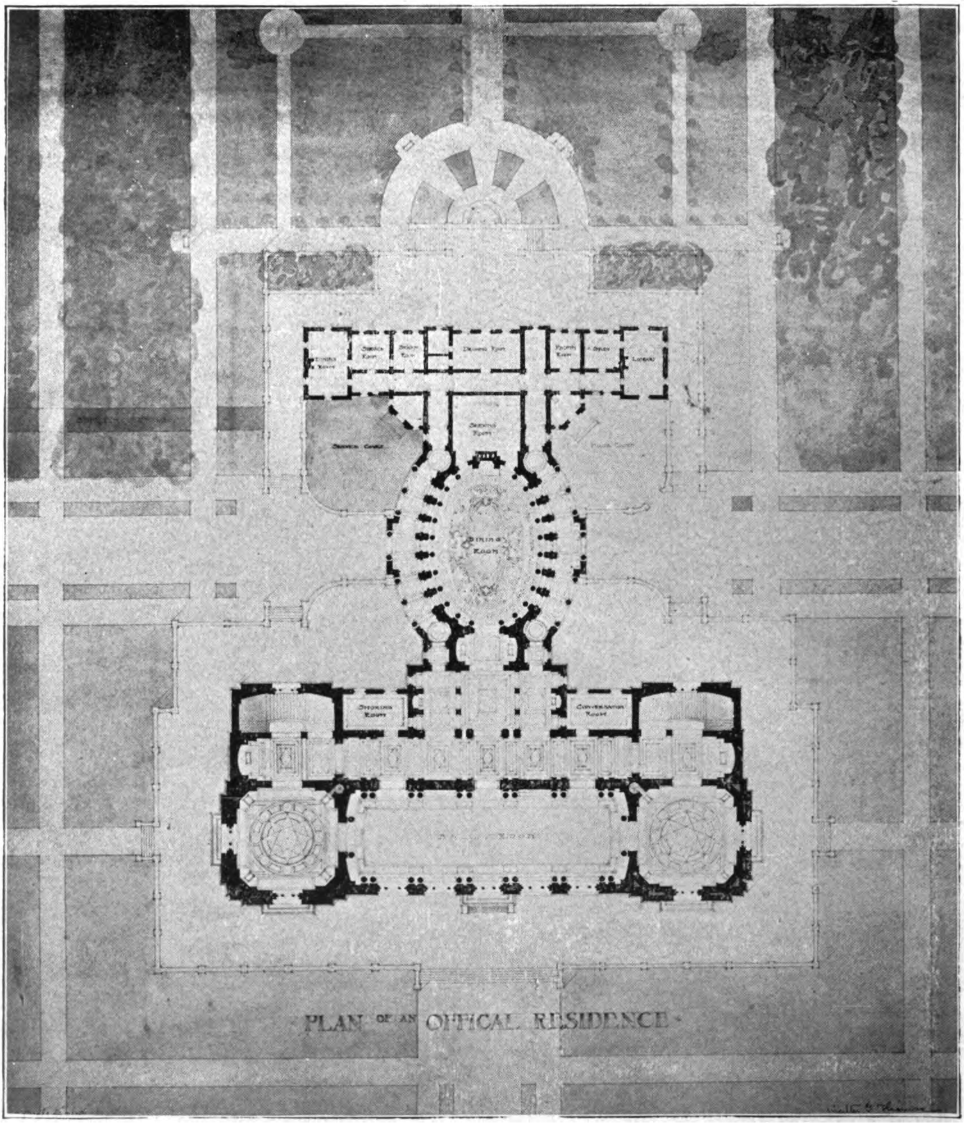
2nd Year Work. A PUBLIC LIBRARY. S. F. Kimball.



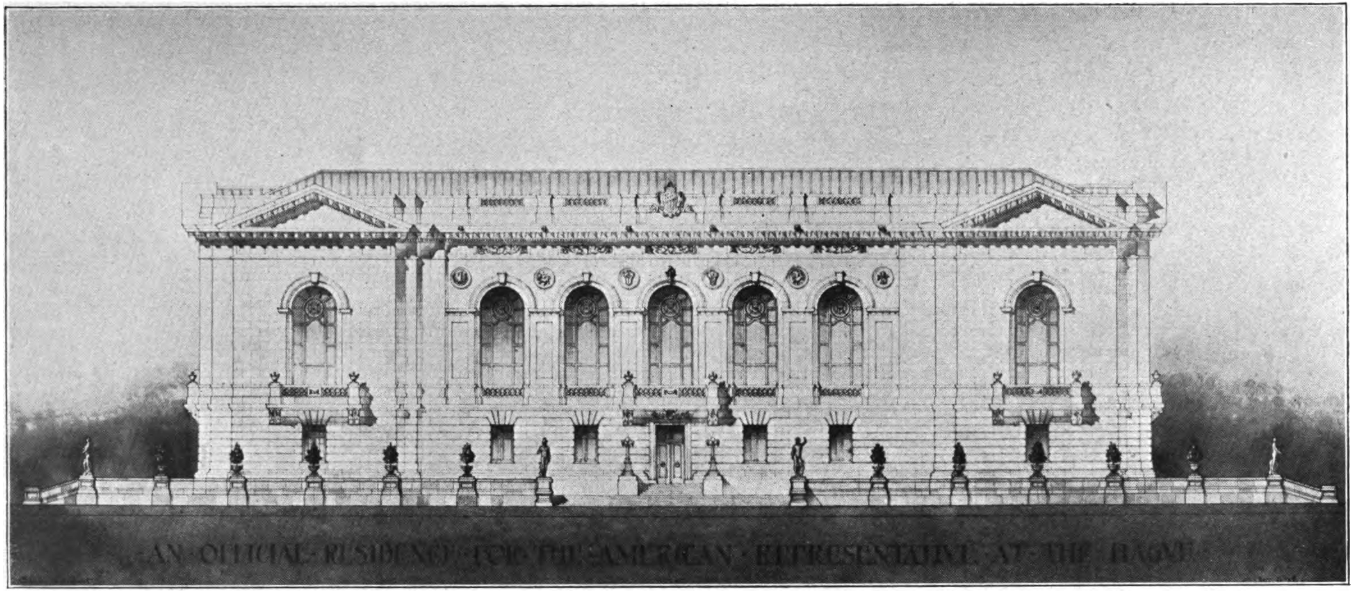
3rd Year Work. A HUNTING LODGE. Edward G. Reed.



3rd Year Work — A HUNTING LODGE. — R. Everett.



4th Year Work. AN OFFICIAL RESIDENCE. W. G. Thomas.



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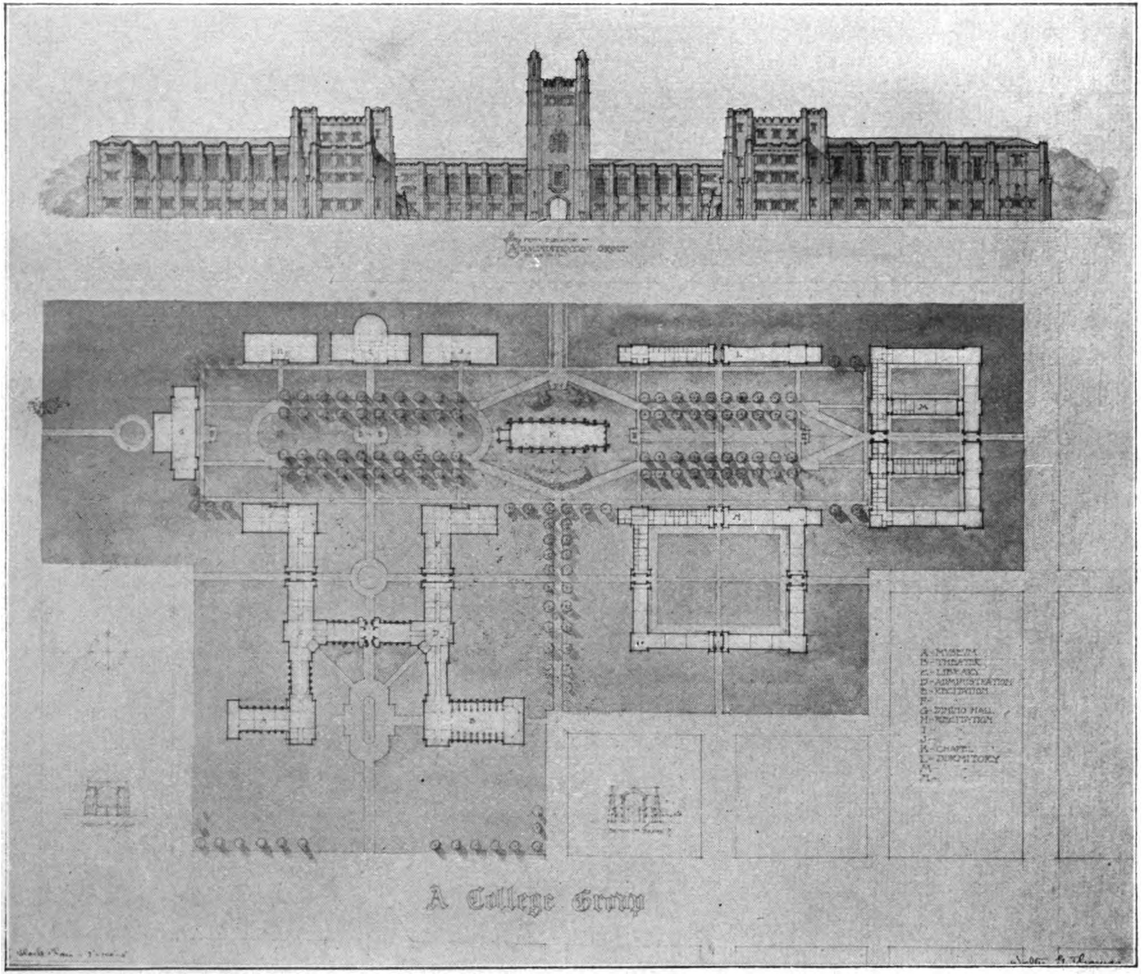
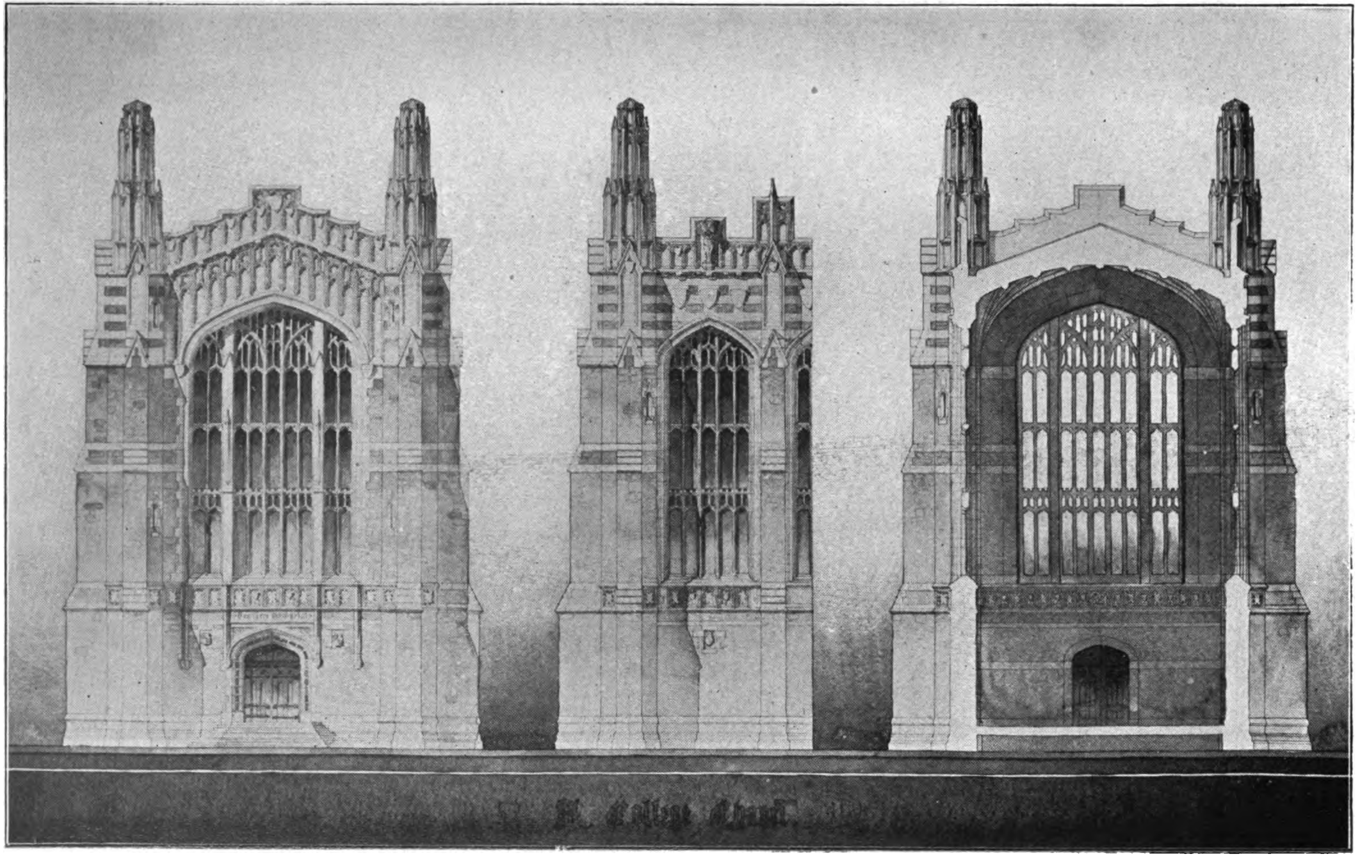
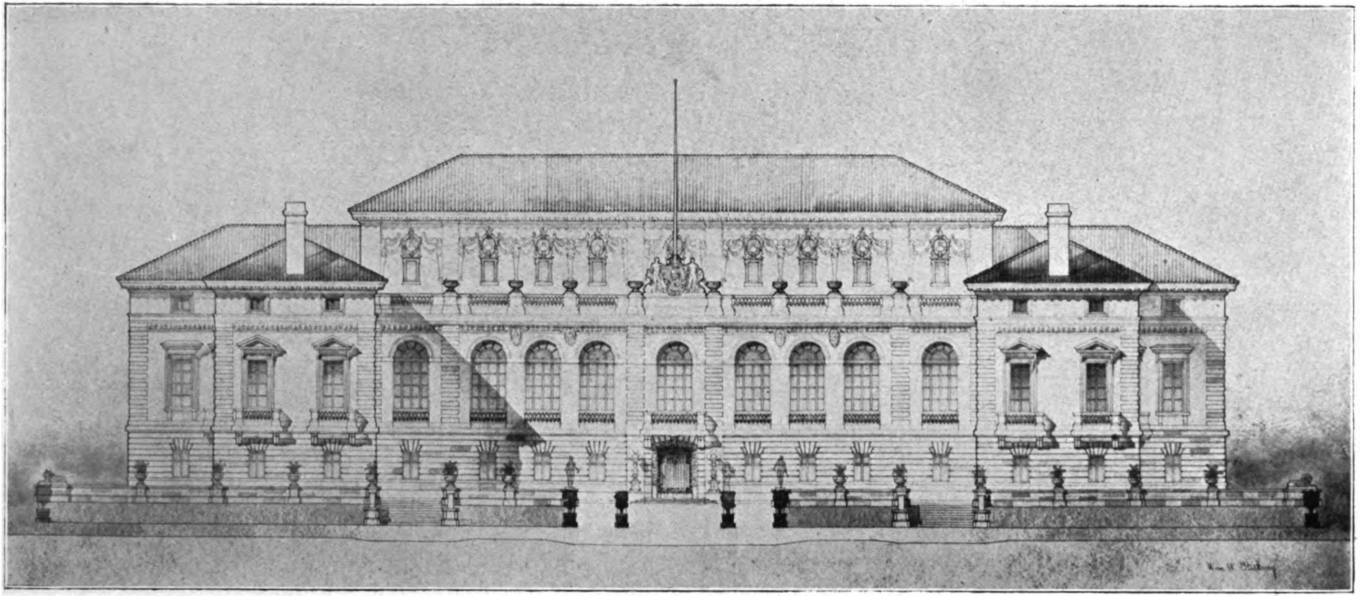


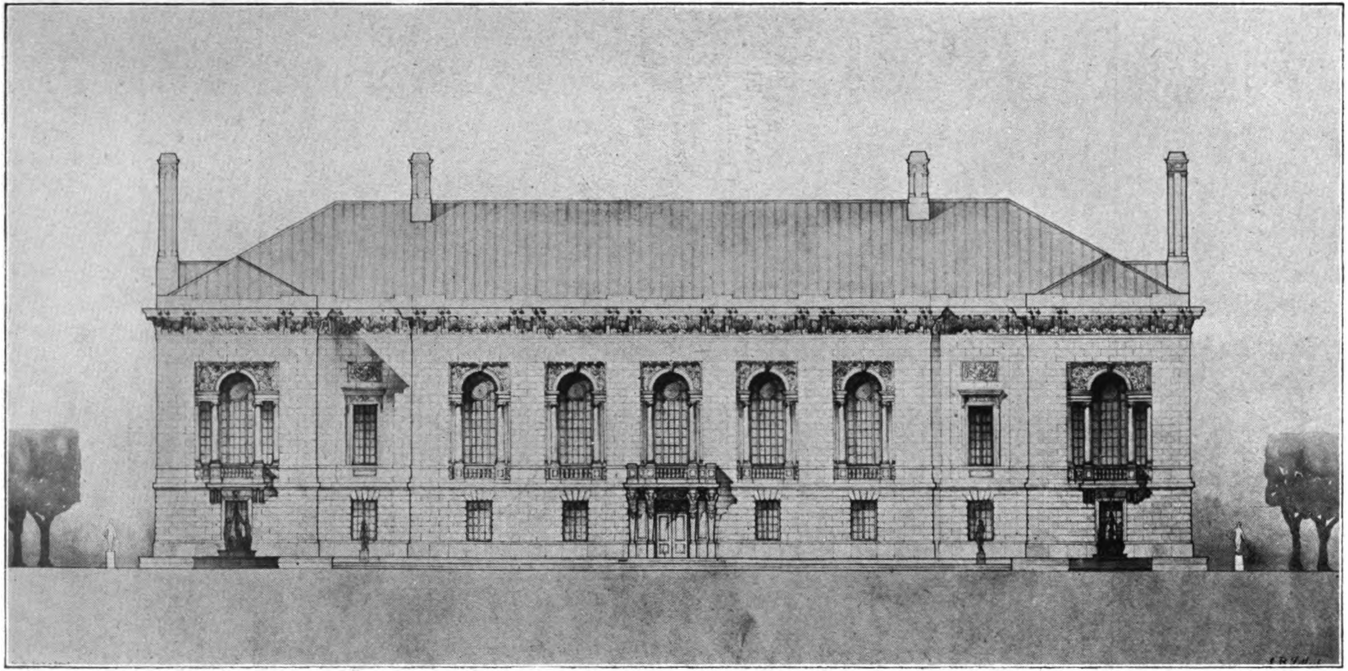
4th Year Work. A COLLEGE GROUP. W. G. Thomas.



4th Year Work. A COLLEGE CHAPEL. M. Feather.



4th Year Work. AN OFFICIAL RESIDENCE. W. W. Stickney.



4th Year Work. AN OFFICIAL RESIDENCE. S. B. Lothrop.

HARVARD ENGINEERING JOURNAL.

A QUARTERLY

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY.

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.

Subscription Rates.

Per year, in advance	$1.00
Single copies	.35

Address all communications:—

HARVARD ENGINEERING JOURNAL,
Room 218, Pierce Hall,
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.

EDITORIAL.

The series of articles on "Modern Stage Scenery," by Frank C. Brown, is completed this month. Mr. Brown has put a great deal of time into this work, and has produced some very interesting and instructive papers. The illustrations ought to be of particular interest to members of the architectural division.

We are greatly indebted to Mr. Brown for the splendid work he has done for the JOURNAL.

The JOURNAL notes with pleasure the formation of the Harvard Engineering Society of New York. It is hoped that more of such societies will be formed in other cities where the number of Harvard men interested in engineering may warrant.

The suggestions made at the annual dinner of the Engineering Society have certainly been acted upon. The committee appointed at that time has been busy and will have some definite plans to offer the graduates at commencement time. The Harvard men in New York report considerable progress in the organization of their branch. In view of all these facts, the JOURNAL considers this an opportune moment in which to suggest to the graduates that the columns of the paper are always open to them. We are always glad to receive articles of all kinds. Furthermore, we trust that alumni will co-operate with us in introducing a column devoted to items of interest concerning the progress of different graduates. Such a page would be very helpful in keeping the graduates in touch with each other and in giving the undergraduates an idea of what they have before them.

SENIOR "FINAL DINNER."

On Monday evening, May 21, the Seniors in the Department of Engineering held their last dinner of the year in the Trophy Room of the Union. In spite of the fact that this was probably the last time that the Seniors are to be together as undergraduates, the utmost cheerfulness and merriment prevailed.

Dean Sabine, who was the guest of the evening, was introduced as the first speaker. He gave a most timely and interesting talk on the manner in which the MacKay bequest would come into the active possession of the Department of Engineering. This department, he said, would, in a few years, rank among the foremost technical schools of the country.

A precedent was established, it is hoped, in the election of a permanent class secretary, whose duty it will be to keep himself informed about each man in the class and to keep this information for the benefit of the class. This will be of great

service, not only to the men themselves, but also to the Graduate Secretary of the Engineering Society. Howard Turner was elected to this office.

The dinner was notable for the many brilliant speeches and the spirit of cordiality which existed between the undergraduates and the professors.

The following is a list of the speakers:

Professor Hollis	T. J. Hanlon
Dean Sabine	H. M. Turner
Professor Johnson	C. J. Mundo
R. D. Thomson	Professor Kennelly
Professor Adams	C. B. Lewis
C. E. Devonshire	R. H. Harris
Professor Hughes	Professor Reeve
R. Sickles	F. R. Pleasonton
L. W. Hayes	Professor Kennedy

CIVIL ENGINEERING CLUB.

The Civil Engineering Club held its last meeting of the year on Wednesday, May 22. Mr. A. T. Safford of the "Locks and Canals Company of Lowell" gave a very interesting talk on Modern Water-Power Plants. The following were elected officers for next year: B. H. Quinham, president; and J. F. Johnson, secretary. The treasurer is to be elected at the first meeting of next year.

HARVARD ELECTRICAL CLUB.

The last meeting of the year was held in Hollis 11, on Tuesday, May 21. Mr. J. H. Shuman of the Boston Elevated Railroad spoke on "Rolling Stock Equipment in Relation to Generator Station Capacity," dealing particularly with "space-time" curves to show the probable load on a given system running scheduled trains which stop at regularly stated points.

The following officers were elected for the coming year:

C. C. Pope, *President.*
Lester Bangs, *Secretary.*

THE HARVARD MECHANICAL CLUB.

At the March meeting of the Mechanical Club, Mr. F. W. Turner of the Mechanic Arts High School of Boston, well known to some of the older members of the club through their acquaintance with him during their shop courses at the Rindge Manual Training School, gave an interesting account of the development of machine tools from the use of the primitive implements of the earliest times to the highly perfected machining mechanisms of to-day. His explanation of the part played by the so-called "high speed" steels in this development was especially good.

The thanks of the club were extended to Mr. Turner, who came in answer to a telephone call sent him the same evening on which he spoke, the speaker who had been expected being detained by sickness in his family. Mr. Turner spoke to the club at its meeting in November, 1900.

Prof. S. A. Reeve, M.E., of the Worcester Polytechnical Institute, who is filling Prof. Lionel S. Mark's place in the Engineering Department, spoke to the club at the April meeting on his "Experiences with Refrigerating Machinery," the material for the entire talk being taken from his own personal experiences. It was especially valuable, owing to the fact that those features of refrigeration that are failures, were fully described, and the reason for these failures plainly made evident. Much that is not available in the literature on the matter of refrigeration was thus presented in a very instructive way.

The annual election of officers was held at the April meeting, and Julian Tyng, '08, was elected president; Chester C. Rausch, '09, secretary, and John Coleman, '10, treasurer. The reports given showed last year to have been one of the most profitable and successful in the history of the Mechanical Club.

CHESTER C. RAUSCH, *Secretary.*

HARVARD ENGINEERING SOCIETY.

At a recent meeting, Mr. C. M. Harrington, '05, who has been working with Prof. Johnson on concrete investigations, gave an address, treating of Jamaica, and dwelling especially upon the recent earthquake there, and its effect upon engineer-

ing structures. Mr. Harrington used stereopticon views which he made himself, during his recent work there.

After the address, the annual election of officers was held, the following being elected: President, George A. McKay, '08; Secretary, Elmer L. Ford, '08; Treasurer, Warren B. Strong, '10; Graduate Secretary, Harry P. Forté, '07; Advisory Member, Prof. I. N. Hollis.

At that meeting, a committee, composed of O. W. Hartwell, '08, and C. C. Rausch, '09, was appointed by the president, to make arrangements for the annual picture of the society. This picture was taken Wednesday, May 15, on the steps of Pierce Hall, and those desiring copies may obtain them from the committee or Mr. Pach, the photographer.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NOVEMBER, 1907

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Vol. VI TABLE OF CONTENTS No. 3

Frontispiece (Fig. 4). See page 95.

HARVARD ENGINEERING JOURNAL

A QUARTERLY

Devoted to the interests of Engineering and Architecture of Harvard University

VOL. VI NOVEMBER, 1907 NO. 3

"THE SUBWAY," NEW YORK CITY.

BY STEPHEN U. HOPKINS, S.B., '97,

ASSISTANT ENGINEER, PUBLIC SERVICE COMMISSION FOR FIRST DISTRICT, NEW YORK CITY.

The articles on the New York "Subway," by Mr. Hopkins, the first of which appears in this issue, should be of great interest to the readers of the "Journal," in that they will outline in general, and describe particular features of the constructed portion of the most comprehensive system of municipal rapid transportation ever planned, and will probably give some idea of its magnitude and the difficulties attendant upon its construction. The successful completion of this work is in great measure due to an efficient Board of Commissioners and its freedom from political influences, to a well organized Engineering Department and the ability and devotion of the engineers.

GEORGE S. RICE, '70,
Chief Engineer.

History of Rapid Transit in New York. — The completion of the "Subway," contract No. 1, marked the solution of a problem which has baffled the people of New York City for over thirty-five years. As early as 1866 it was realized that the horse-car lines were becoming entirely inadequate, and in 1868 the New York City Central Underground Railway Company was incorporated by forty-two well-known business men, to build a line from City Hall to the Harlem River. In 1872 Cornelius Vanderbilt and others incorporated as the New York City Rapid Transit Compay to build an underground road from City Hall to connect with the New York & Harlem Railroad

at 59th Street, with a branch to the tracks of the New York Central Railroad, and a perpetual franchise was granted to the company. A few years later other grants for underground roads were made by the legislature, but all to no purpose, so far as underground construction was concerned.

The elevated steam railroads were constructed in 1872-79 as a sort of substitute for an underground road. These elevated roads are ungraceful structures, noisy, and an unsatisfactory means of transit, which will some day be abolished by an enlightened city.

In 1888 Mayor Abram S. Hewitt endeavored to secure "Subway" legislation, but his bill found practically no support. In 1891, however, the city secured the passage of a Rapid Transit Act, in which a commission was named. This act provided that plans for a railroad having been prepared in general and in detail, consents of abutting property owners obtained, etc., the commissioners might sell at public sale, to a corporation whose powers and duties were defined in the act, the right to build and operate the road for such a time and at such terms as they could obtain. The property owners refused to consent, and it was necessary to get the approval of the Supreme Court in lieu thereof. Bids were finally invited, but there was no responsible bidder.

In 1894 the Rapid Transit Act was remodeled and a new Board of Commissioners named. The question of municipal construction or construction by a corporation under a franchise was to be decided by a popular vote. Over 90,000 majority declared for municipal ownership and construction. Embodied in the bill were some impossible conditions. For instance, a bidder for the contract to build the "Subway" was compelled, under the act, to deposit $1,000,000 in cash and to furnish a bond, which was later fixed at $15,000,000. The necessity of going before the legislature to secure amendments, and the small margin of the city's available funds, on account of the "debt limit," held the matter in abeyance until 1900. The contract under which the present "Subway" was built was executed between the city and John B. McDonald on Feb. 21, 1900. The amount to be paid by the city for the construction under contract No. 1 (see plan and profile) was $35,000,000,

proceeding.

under contract No. 1 (see pl[illegible]

with an additional amount not to exceed $2,750,000 for real estate necessarily acquired, station sites, terminals, etc., making the total cost of construction $37,750,000. The construction was to be completed within four and one-half years. Under the contract the road was leased to the contractor for a term of fifty years, with the option of renewing the lease for twenty-five years more, the said contractor to furnish at his own expense all equipment for operating the road. The rental for the fifty-year term was fixed at an amount equal to the annual

No. 1. FOUR-TRACK STEEL WORK IN PLACE ON ELM STREET, BETWEEN READE AND DUANE STREETS.

interest on the bonds issued by the city for construction and one per cent additional, such one per cent during the first ten years to be contingent upon the earnings of the road. If the earnings should be more than five per cent, the additional one per cent above mentioned should be paid to the city. If the lease should be renewed for the additional period of twenty-five years, the rental, to be agreed upon by the city, should not be less than the average for the ten years immediately preceding.

To secure the performance of the contract, the contractor was required by the city to deposit $1,000,000 in cash as security for construction, to furnish a bond, with surety for $5,000,000, as security for construction and equipment, and further, to furnish another bond for $1,000,000, as continuing security for the performance of the contract.

In addition to the above security, the city has, under the provisions of the Rapid Transit Act, a first lien on the equipment. At the expiration of the lease and renewals (if any) the equipment is to be turned over to the city pending an agreement or arbitration upon the price the city shall pay for said equipment.

Arrangements for Carrying Out the Contract. — When McDonald's bid was accepted by the city, no arrangements had been made by him for the capital necessary to carry out the contract, and at first he found little encouragement in his efforts to secure the capital. The surety companies refused to furnish the security required of him by the city except on terms impossible of fulfillment. These companies only reflected the general attitude of business and railroad men towards the projected "Subway," for there were comparatively few people who thought such gigantic construction, underground in New York City, feasible.

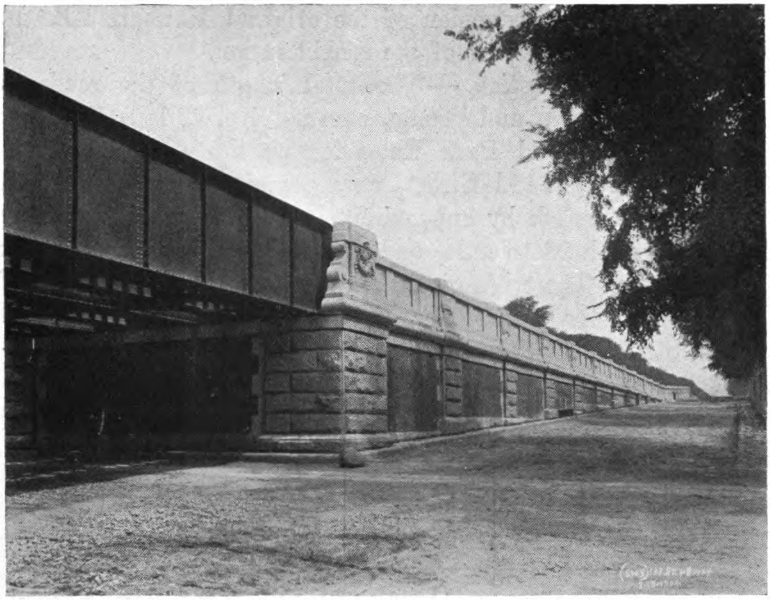
Mr. McDonald sought help from several capitalists and corporations in vain, and failure seemed inevitable. He finally sought the assistance of August Belmont, who organized and incorporated the Rapid Transit Subway Construction Company, which furnished the security required for the performance of the contract, furnished the capital necessary to carry on the work, and assumed the supervision of the undertaking. John B. McDonald became a director in this company.

The equipment of the road included, under the terms of the contract, all rolling stock, all power-houses and sub-stations and real estate upon which they should be erected, all machinery and mechanisms for generating the motive power, for lighting and for the signal system, etc.

The magnitude of the task of providing the equipment has generally been overlooked by comparison with the construction work. The equipment and real estate incidental thereto in-

volved an expenditure on the part of the Rapid Transit Subway Construction Company of about $24,000,000. The work of planning for the equipment and operation of the road was begun within six months after the signing of the contract.

In the spring of 1902 the Interborough Rapid Transit Company was formed as an operating company, with the same directors, save one, as the Rapid Transit Subway Construction Company. The lease for operating the road after it should



No. 2. MASONRY APPROACH TO MANHATTAN VALLEY VIADUCT, BROADWAY FROM 133D TO 135TH STREETS, LOOKING NORTH.

be constructed and equipped was assigned by Mr. McDonald to this company.

Contract No. 2 (see map and profile) was awarded to the Rapid Transit Subway Construction Company and was executed by the city with the said company Sept. 11, 1902. This contract, which was similar to contract No. 1, was to build, equip, and operate what may be termed an extension of the Manhattan-Bronx "Subway," contract No. 1, from its southern end at City Hall to Brooklyn. The bid accepted by the city was $2,000,000

for construction and $1,000,000 additional for terminals, etc., — $3,000,000 in all. This contract was most advantageous to the city, since the estimated cost of the completed work was $9,000,000. The contract was accompanied by an auxiliary contract for connections and through service for a single fare with the Manhattan-Bronx "Subway" (contract No. 1). It will be noted that the construction and operating companies are the same for both contracts, which accounts for the exceptionally advantageous terms, the planning of the Manhattan-Brooklyn "Subway" as an extension of the original Manhattan-Bronx "Subway" being a part of the consideration.

General Description. — The total length of the road, as shown on the plan and profile, contract No. 1, is 21.3 miles. The Van Courtland Park Extension on the west side, from 230th Street to 242d Street, now practically complete, will increase this length by approximately 0.86 of a mile, making the total length 22.16 miles and the total length of single track 70.98 miles. The table given below shows the distribution of the work constructed, all of which, except the above-mentioned Van Courtland Park Extension, has long since been in operation.

No. of Tracks	Underground	Viaduct	Total
1 2 3 4	0.4 Miles 6.6 " 1.9 " 6.8 "	0.0 Miles 1.4 " 5.06 " 0.0 "	0.4 Miles 8.0 " 6.96 " 6.8 "
Total	15.7 Miles	6.46 Miles	22.16 Miles

The underground work may be subdivided into work done in open cut, or "cut and cover," and in tunnel, as shown in the following table:

	Subway (Cut and cover)	Deep Tunnel	Harlem River Tunnel	Viaduct	Total
Underground	11.88 M	3.7 Miles	0.12 Miles		15.7 Miles
Viaduct				6.46 M	6.46 Miles
Total	11.88 M	3.7 Miles	0.12 Miles	6.46 M	22.16 Miles

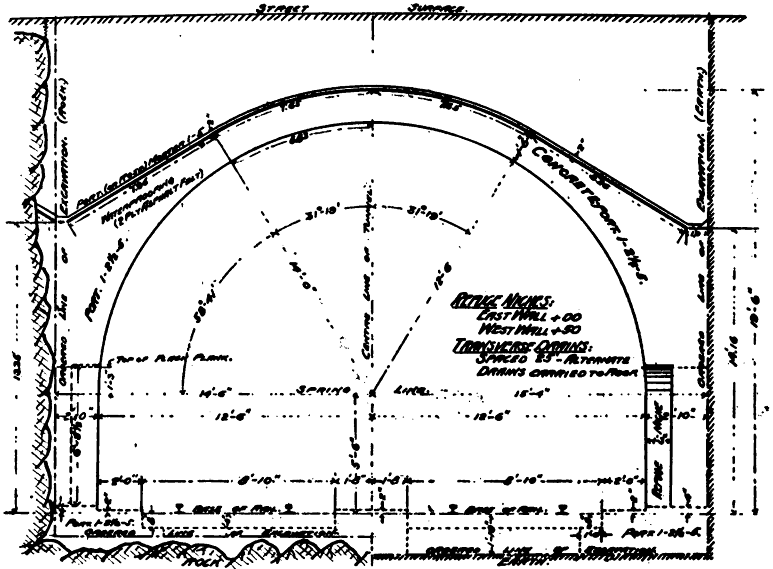
The work of building the "Subway" was formally begun March 24, 1900, and the main portion of the road was opened to the public Oct. 27, 1904, four years and seven months after the formal beginning.

The main work of construction was divided by the contractor into fifteen sections (shown on plan and profile), the length of which were determined by local conditions and the character of the construction. The work thus divided was sub-let to eleven

No. 3. BROADWAY, AT 66TH STREET, LOOKING NORTH, SHOWING SOME OF THE PIPES AND PREPARATION FOR CHANGING AND SUPPORTING THEM.

sub-contractors. The main sewer work, off the line of the "Subway," was sub-let to three sub-contractors. In addition to these sub-contractors for the main construction, sub-contracts for material and work have been let from time to time.

The enumeration of the various sub-contractors would in itself give some idea of the magnitude of the work, but the scope of this article will not permit of such an enumeration. The following list, however, gives the number of principal sub-contractors for the more important parts of the work.



TYPICAL SECTION OF TWO TRACK ARCH CONSTRUCTION IN EARTH AND ROCK OPEN CUT

SECTION 13, 3RD DIVISION.

SCALE: 5' = 1". NOV. 14TH 1901.

Main construction work (fifteen sections and extensions)	15
Sewer construction not along line of work.............	3
Finish work on stations..............................	25
Track and track material.............................	13
Material for main construction not furnished by sub-contractors for sections..............................	10
Electrical equipment	27
Mechanical equipment, power-house, sub-stations, etc., included	43
Rolling stock and signal equipment...................	22
Total..................................	158

There were many more sub-contracts for less important parts of the work, but the above list will give some idea of the volume of detail and the amount of supervision required.

Design and Supervision of Construction.—Under the Board of Rapid Transit Railroad Commissioners representing the city of New York, the engineering department was organized as follows: The general supervision of all construction and designing work was vested in a chief engineer and a deputy chief engineer. The route of the "Subway" was divided into four divisions, and the sewer work incidental to the construction formed another division. Each division was in charge of a division engineer. In addition to these, there was a division of designs and a division of material inspection, in charge of a general inspector of designs and a general inspector of material respectively. Each division, except the division of designs, which was located in the chief engineer's office, was equipped with a main office and portable sub-offices. The sub-offices of the general inspector of materials were located at the various plants of the steel and cement companies. The staff of a division engineer consisted of a senior assistant engineer and from two to four assistant engineers in charge of construction of a certain section or sections into which the division was subdivided, corresponding to the contractors' sections shown on the plan and profile. Each assistant engineer of construction had a corps of assistant engineers, rodmen, axemen, and inspectors.

The personnel of the chief engineer's staff from the beginning of the work to Dec. 31, 1904, with one exception, was as follows:

Wm. Barclay Parsons	Chief Engineer
George S. Rice	Deputy Chief Engineer
Albert Carr	Engineer First Division, 3.5 Miles
Alfred Craven	Engineer Second Division, 3.8 Miles
Beverly R. Value	Engineer Third Division, 8 Miles
Eugene Klapp	Engineer Fourth Division, 5.5 Miles
Calvin W. Hendrick	Engineer Sewer Division
St. John Clarke	General Inspector of Designs
W. A. Aiken	General Inspector of Materials

Beverly R. Value resigned March 1, 1903, and was succeeded by C. V. V. Powers.

The present staff is as follows:

George S. Rice	Chief Engineer
Alfred Craven	Deputy Chief Engineer
Geo. H. Clark	Engineer First Division
John H. Myers	Engineer Second Division
C. V. V. Powers	Engineer Third and Fourth Divisions
Frederick C. Noble	Engineer Fifth Division
Amos L. Shaeffer	Engineer of Sewers
Dverre Dahm	General Inspector of Designs
D. L. Turner	General Inspector of Stations
W. A. Aiken	General Inspector of Materials

The above-mentioned Board of Rapid Transit Railroad Commissioners was superseded July 1, 1907, by the Public Service Commission for the First District, a board of five members appointed by the governor.

The limits and location of the divisions have been changed since the completion of work under contract No. 1, so as to embrace work let under contract No. 2 and later contracts and extensions.

Contract No. 2 (see map and profile), a part of which is being operated and the remainder nearing completion, was executed as before stated Sept. 11, 1902, but since this contract provided that no street excavation was to be made until the

steel for the framework was delivered, excavation did not begin until Sept. 23, 1903. The route thus contracted for is 3.47 miles long, with 7.6 miles of single track. The distribution is as follows:

No. of Tracks	Length
2	2.82 Miles
3	0.65 Miles
Total	3.47 Miles

The above 3.47 miles is divided according to character of construction, as follows:

	Miles
Open excavation (roofed over during construction).....	2.23
Cast-iron lined tubular tunnels........................	1.24
Total......................................	3.47

Of the above 1.24 miles of cast-iron lined tubular tunnel, 1.13 miles is beneath water level of East River, with a maximum depth of 96 feet. The open cut excavation shown above was not actually an open cut, as it was required to be roofed over and the street surface maintained from curb to curb, and without interruption to traffic. Since a part of this work was under lower Broadway from the Post-office to the Battery, the difficult nature of the work may be understood.

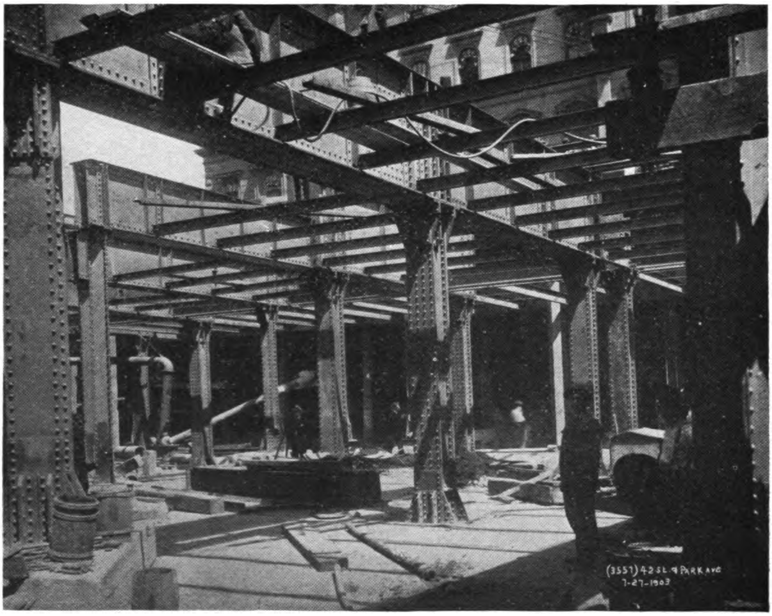
The portion of contract No. 2 extending from the Post-office to the Battery has been in operation in connection with the original Manhattan-Bronx Road since July, 1905.

The total work of contracts Nos. 1 and 2 may be summarized as follows:

	Subway (Cut and cover)	Deep Tunnel	River Tunnel Cast Iron Lined	Viaduct	Total
Contract No. 1	11.88 M	3.7 Miles	0.12 Miles	6.46 M	22.16 M
Contract No. 2	2.23 M		1.24 Miles		3.47 M
Total	14.11 M	3.7 Miles	1.36 Miles	6.46 M	25.63 M

Of the above 25.63 miles of road under contracts Nos. 1 and 2, 22.6 miles are under operation at present, and the remainder is nearing completion. The length of single track is 70.98 miles for contract No. 1, 7.59 miles for contract No. 2; total, 78.57 miles.

General Construction. — The governing idea in the design of the road was to keep the structure as near the surface of the street as possible, the main reason for this design being



No. 4. PARK AVENUE AND 42D STREET, SHOWING THE EXTRA HEAVY COLUMNS AND GIRDERS IN PLACE TO SUPPORT THE HOTEL BELMONT, WHICH IS BUILT PARTLY OVER THE SUBWAY.

that it conserves the convenience of passengers and facilitates the work of handling the people, on account of the ease and quickness of access from the street surface; besides, the construction work is quicker. This type of construction obtains except where the rugged topography prohibits. Ordinarily the roof of this type of structure is within 5 or 6 feet of the street surface, thus making the excavation about 21 feet deep and bringing the platforms of the stations within about 16 feet of

the surface. The principal aim of the general plan was to obtain speed in handling traffic, and the feature of operation is the express service. On the four-track portion of the road from Brooklyn Bridge to 96th Street there is both express and local service, with express stations 1.5 miles apart.

From South Ferry (Battery) to Brooklyn Bridge the structure is a two-track subway construction, in a cut roofed over with timber, so as to maintain the street surface from curb to curb. From Brooklyn Bridge to 33d Street the structure is a four-track subway, constructed in open cut. From 33d to 42d Street the construction is two double-track, concrete lined, tunnels, one on each side of the Park Avenue Tunnel of the Metropolitan Street Railway, but at a considerably lower level (see contract drawing C 9). Through 42d Street to Broadway and up Broadway to 96th Street there is a four-track subway, built in open cut. From 96th Street to 103d Street the construction is a four-track subway, built in open cut, but the two middle tracks are gradually depressed so as to swing to the east under the east track. From 103d Street, where the two tracks of the east side line swing east under 104th Street and under the northern end of Central Park to 110th Street and Lenox Avenue, the construction is concrete and brick arch, built in tunnel. From 110th Street (Lenox Avenue) to the Harlem River the construction is a two-track subway, built in open cut. Across the Harlem River the construction is two single-track cast-iron and concrete-lined tubular tunnels, built in a coffer dam. From the Harlem River to a short distance east of 3d Avenue the construction is a two-track concrete arch, built in open cut. The remainder of the road to Bronx Park is a two-track elevated structure with an open cut approach.

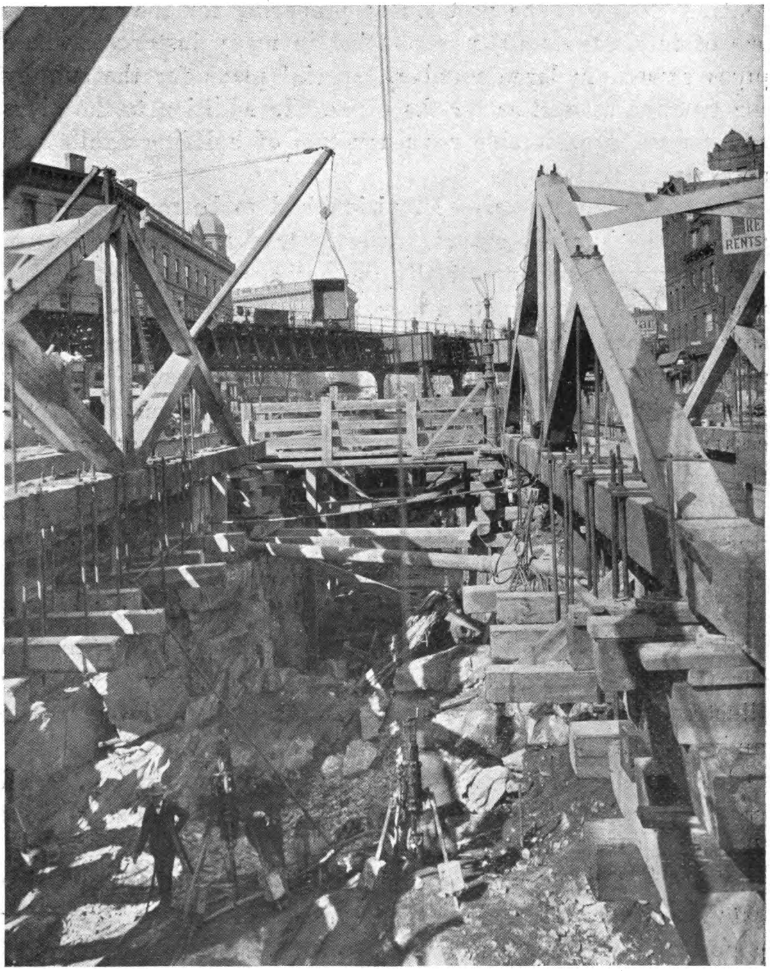
The West Side Line continues up Broadway from 103d to 116th Street as a three-track subway, built in open cut. From 116th Street to 122d Street the structure is a three-track concrete arch (three centered), built in open cut. From 122d Street to 135th there is a three-track viaduct across Manhattan Valley, with an approach at each end constructed as open cut and embankment, with masonry (granite, brick, and concrete) retaining walls. From the portal at 135th Street to 146th Street there is a standard three-track subway, built in open cut,

except between 138th Street and 144th Street, where there is a storage yard of five additional tracks (eight tracks in all). The structure at this point is 102 feet wide. From 146th Street to 151st Street there is a two-track concrete arch, built in open cut. From 151st Street to 202d Street (Fort George) the structure is a two-track concrete arch tunnel (reaching as great a depth as 200 feet), except for open-cut construction between 155th Street and 158th Street, where the 157th Street station is built as a concrete, structural, steel subway with a two-track concrete arch approach at each end. North of the Fort George portal at 202d Street there is an open-cut approach with concrete retaining wall and then a three-track elevated structure to Van Courtland Park at 242d Street. The line crosses the Harlem River on a double-deck truss bridge.

Stations. — There are fifty-four stations on the portion of the road under operation, five of which are express stations. All express stations and the local stations on contract No. 2 are 400 feet long, all other local stations are 350 feet long, except the two deep tunnel stations at 168th and 181st Street, which are 300 feet each. Of the fifty-four stations mentioned above, forty-two are underground.

The finish work of the stations is a feature of the road. Each underground station has a distinctive design and color scheme, but the material used in the finish is the same in nearly all of them. This finish consists of a "norman" brick wainscotting, glass tile walls inlaid with art ceramic bands and name tablets, and terra cotta cornices. Each station is equipped with lavatories for men and women.

Sub-surface Structures, Sewers, Pipes, etc.—The proximity of the structure to the surface made it necessary to change and relay a considerable portion of the sewers and pipes encountered. In fact, the complete reconstruction of the sewerage system along the route was found necessary, involving the building, under contract No. 1, of 7.5 miles of sewers along the route of the railway, and 5.2 miles of sewers in streets other than those followed by the route, making a total of 12.7 miles of sewers built under contract No. 1 alone. In one case (Canal Street) the entire drainage system of an area of 190 acres draining into North River was changed to drain into East



No. 5. BROADWAY AT 64TH STREET, LOOKING NORTH, SHOWING TRUSSES FOR SUPPORTING TROLLEY TEMPORARILY BY MEANS OF "NEEDLE" BEAMS UNDER CONCRETE FOUNDATION OF TRACK YOKES.

In background is the Elevated Railway supported on timbers by means of extension girders.

River, involving the construction of a new six-foot circular sewer a mile long, partly in tunnel.

There were over forty miles of water pipes, gas pipes, electric ducts, etc., reconstructed and moved along the route of contract No. 1. The problem of preparing for the pipes was one of intricate detail, necessitating in many instances, where pipes existed in large numbers, special plans for the subway construction as well as for the pipes. In addition to the pipes and sewers, considerable reconstruction of building vaults was necessary.

Surface Structures. — Provision had to be made for supporting the surface electric railway tracks of conduit type, which extend along practically the entire route of the railway where subway construction was used. At Union Square the surface tracks with their trolley yokes extending 2.5 feet underground were temporarily diverted to one side instead of being supported in place. This diversion, which was considered necessary on account of the character of the rock encountered, cost the contractor about $20,000.

The route as built crosses under the elevated railway at five different points, at four of which the elevated structure was underpinned and new foundations put in.

In addition to supporting the surface and elevated tracks, buildings had to be shored and supported temporarily, and in some cases new foundations constructed. A rather spectacular illustration of this sort of work was where the subway passed under a part of the foundation of Columbus Monument at Columbus Circle. This monument is a marble shaft of small cross-sectional area, seventy-five feet high, and weighing about 724 tons.

The monument was "shored," and a part of the foundation extended below sub-grade. The subway structure extends under a part of the monument foundation.

Quantities. — Below is given a table showing approximate total quantities of work done under the principal items of construction, contract No. 1, including extra work and terminals, but does not include the extension of the elevated structure to Van Courtland Park, .86 mile.

Earth excavation (cubic yards)	2,000,000
Rock excavation (cubic yards)	920,000
Tunneling (cubic yards)	380,000
Shaft excavation (cubic yards)	7,200
Concrete (cubic yards)	595,000
Pedestal masonry (cubic yards)	4,900
Cut-stone masonry (cubic yards)	1,900
Brick masonry (cubic yards)	31,200
Steel erected (tons)	74,500
Cast iron erected (tons)	4,500
Track laid (linear feet)	369,600
Electric ducts laid (linear feet, single)	6,675,000

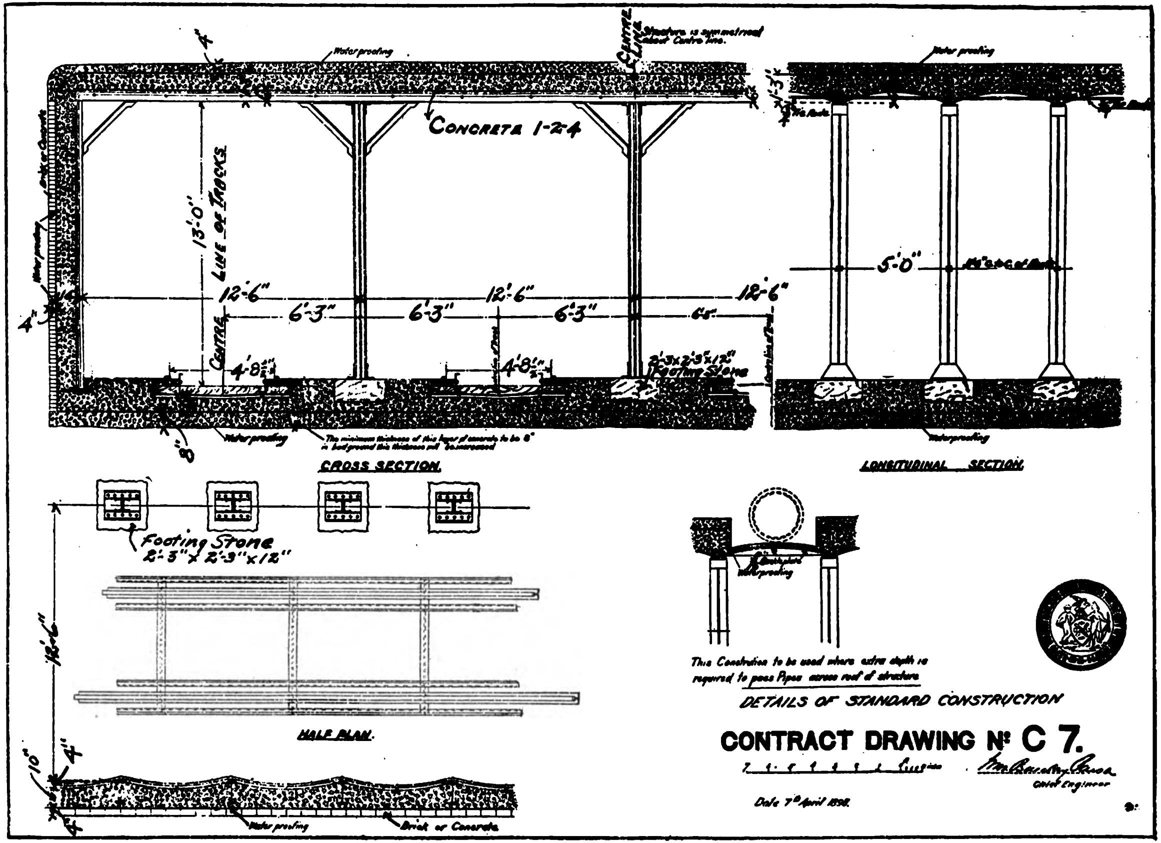
Cost. — The approximate total cost of the Rapid Transit Railroad known as the "Subway," as constructed under contract No. 1, including extensions and extra work, is as follows:

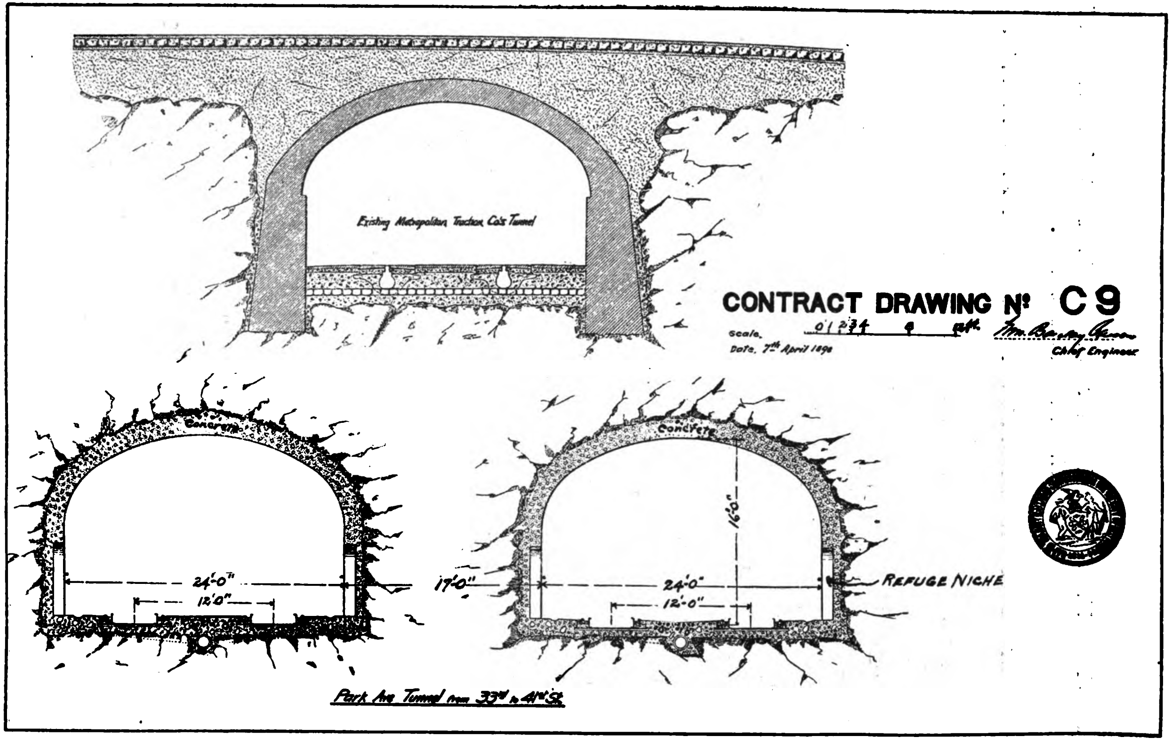
Contract price of construction	$35,000,000
Contract price for terminals, real estate, etc.	2,750,000
Extra work, extensions, etc. (approximate)	4,700,000
Cost to city of New York	$42,450,000
Equipment, contractor's expense (estimated)	24,000,000
Total cost construction and equipment	$66,450,000

The cost of equipment includes power house plant sufficient to operate contract No. 2.

The average number of men employed daily during the three years when construction work was at its height was about seven thousand.

This roughly outlines the work of the largest single contract ever let, and a part of the route and plans of the most comprehensive system of rapid transit ever devised.


Concrete 1-2-4
Centre Line of Tracks
Structure is symmetrical about Centre line.
Water proofing
Brick or Concrete
Footing Stone 2'-3" x 2'-3" x 12"
The minimum thickness of this layer of concrete to be 6" in bad ground this thickness will be increased
CROSS SECTION.
LONGITUDINAL SECTION.
HALF PLAN.
This Construction to be used where extra depth is required to pass Pipes across roof of structure
DETAILS OF STANDARD CONSTRUCTION
CONTRACT DRAWING No. C 7.
Chief Engineer
Date 7th April 1898.


CONTRACT DRAWING Nº C 9
Scale, 0 1 2 3 4 8 ft.
Date, 7th April 1898
Chief Engineer
Existing Metropolitan Traction Co's Tunnel
Concrete
24'-0"
12'-0"
17'-0"
16'-0"
Refuge Niche
Park Ave Tunnel from 33rd to 41st St.

PRELIMINARY WORK ON APPARATUS FOR TESTING FLAT CAST-IRON PLATES.

BY SIDNEY WITHINGTON, '06. FRANK RODNEY PLEASONTON, '06.

Last winter, there was begun, in the engineering laboratory, a series of experiments to determine the breaking load on flat circular plates of various thicknesses, with "fixed" edges. The mathematical discussions of this subject are unsatisfactory, because of the very complicated stresses set up in a plate when subjected to a load. Several formulas have been deduced, but all are unreliable, and do not represent actual conditions. It should be possible in this, as in other problems, to find a general rule mathematically, and to modify this form of formula by coefficients, etc., based on experiments. One of the difficulties is that few tests have been made on this subject, and experimental data is very scarce.

The general method of the procedure followed in testing the plates was:

1° The construction and assembly of suitable apparatus.

2° The measurement and preparation of the plates.

3° The calibration of instruments.

4° The insertion of the plates and final adjustment of the apparatus.

5° The gradual application of uniformly distributed normal pressure and careful observation of the deflections of the exposed surfaces of the plates, corresponding to suitable increments of pressure.

6° The preparation of test specimens and apparatus for an investigation of the ultimate tensile, compressive, and flexural strengths of the material of the plates and of the strains produced by different intensities of stress.

7° The performance of the experiments necessary for such investigation.

8° The plotting of representative curves based upon data afforded by the observations of deflection.

The apparatus consists of:

1° An hydraulic cylinder and piping.
2° A hand pump.
3° A steam pump.
4° Two pressure gauges.
5° A pressure scale.
6° A bridge.
7° Four micrometer-heads.
8° An extensometer.
9° Three testing machines.
10° Electrical apparatus.

The hydraulic cylinder is a partially machined, heavy, gray-iron casting, of sufficient thickness to withstand internal fluid pressures of 5,000 or 6,000 pounds per square inch. The pipe connecting the pump and the cylinder is a section of extra heavy hydraulic tubing, that connecting the pressure gauge to the cylinder is a section of ½-inch standard wrought-iron piping, and that connecting the pressure scale to the cylinder is of 1-16-inch seamless copper tubing. All threads and fittings are standard.

The Knowles steam pump is of a standard design for producing high hydraulic pressures. Its capacity is 8,000 pounds per square inch in the water cylinder. It is outside packed.

The 600-pound per square inch pressure gauge is of the commercial Bourdon type, manufactured by the Crosby Steam Guage and Valve Company. It is graduated by increments of 5 pounds per square inch from atmospheric — to 600 pounds per square inch above atmospheric pressure. The 3,000-pound guage is also of the Bourdon type, manufactured by the Crosby Company. It is graduated by increments of 10 pounds per square inch.

The Crosby fluid pressure scale is an instrument designed primarily for testing gauges. The fluid pressure acts upon a plunger of known area, which transmits the thrust upon it through a suitable train of reducing levers to one end of the scale arm, where the pressure is balanced by a simple manipulation of the poise. The plunger is caused to rotate by spinning a hand-wheel, in order that the effect of friction may

almost entirely disappear. The pressure is transmitted through the gauge standard and a spiral copper tube to the base of the plunger.

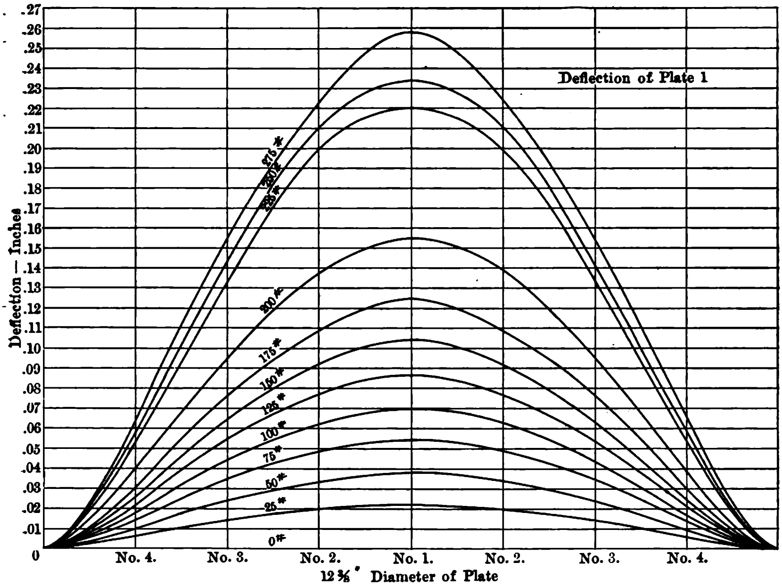
The bridge designed to carry the micrometer-heads is of hard brass and is supported by three adjustable, pointed steel screws, which are electrically insulated from it by vulcanite fiber bushings. The screws rest on, (1) a center punch mark, (2) a hardened tool steel flat surface, (3) a grove chipped in the cast-iron flange, respectively, for each of the two positions of the bridge. The micrometers are held firmly in a vertical position by set-screws. Four micrometers are thus so supported that they may be operated vertically above the exposed surface of the plate in such a manner that its upward deflections may easily be observed. By suitable connection, an electrical signaling system is utilized, its circuit being closed and a small bell caused to ring by contact of any one of the micrometer-heads with the surface of the plate.

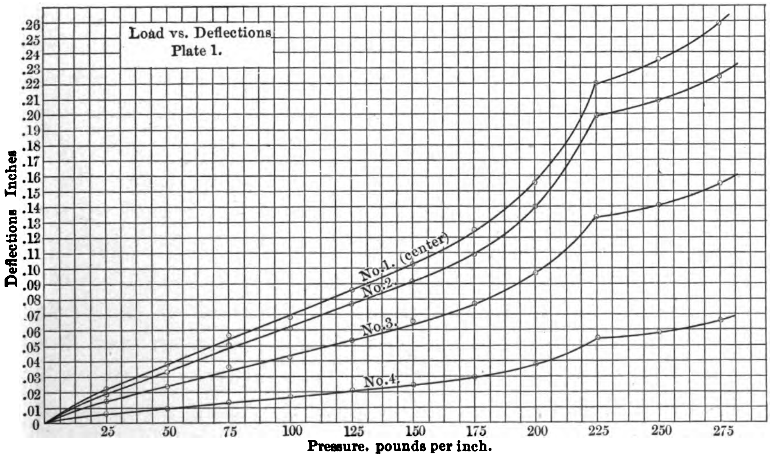
The micrometers used are No. 1 "micrometer-heads," graduated to read to .0001 inch, made by the Brown & Sharpe Manufacturing Company.

In the tension tests the elongations of the specimen under load were recorded by a slight modification of Marshall's micrometric extensometer, which employs electric signaling apparatus similar to that used by the bridge.

The testing machines are those contained in the laboratory and are: (*a*) For tension, a small hydraulic machine built by Riehlé Brothers of Philadelphia; capacity 60,000 pounds; (*b*) for compression, an electrically operated machine built by Tinius Olsen & Co. of Philadelphia; capacity 200,000 pounds; (*c*) for flexure, a " dead weight " machine, built by W. J. Keep of Detroit; capacity 1,400 pounds.

It had been intended to bring pressure upon the plates by first carefully filling the cylinder with water at 40° F. in such manner that no air should be imprisoned when the plates were finally adjusted, and then heating the water to such a temperature that the volumetric expansion of the mass would produce the desired compressive unit load. This was to be accomplished by using steam heat, and to do this connections were made with the steam mains so that it was possible to turn live steam into


Deflection of Plate 1
Deflection — Inches
.27
.26
.25
.24
.23
.22
.21
.20
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
275#
250#
225#
200#
175#
150#
125#
100#
75#
50#
25#
0#
No. 4. No. 3. No. 2. No. 1. No. 2. No. 3. No. 4.
12⅜" Diameter of Plate


Load vs. Deflections
Plate 1.
Deflections Inches
.26
.25
.24
.23
.22
.21
.20
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
No. 1. (center)
No. 2.
No. 3.
No. 4.
25 50 75 100 125 150 175 200 225 250 275
Pressure, pounds per inch.

a condensing tube extending into the interior of the cylinder. The tube, a short section of heavy hydraulic pipe, was closed at the inner end. Its function was entirely that of surface condensation.

Results by this method, however, were not forthcoming, owing to excessive leakage, and the chief source of this was the plate itself, for water passed through it with comparative ease at the first manifestation of pressure. This method, therefore, was discarded as infeasible, and, in its stead, there was at first substituted hydraulic pressure obtained from the small single-acting hand-pump, this pressure being indicated on the 600-pound gauge.

After testing the first plate, the apparatus was rearranged. There was substituted, in place of the hand-pump, the double-acting steam pump, and in place of the 600-pound per square inch commercial gauge, the Bourdon gauge reading to 3,000 pounds per square inch above atmospheric pressure. The "pressure scales" were also added for the second test.

The method adopted in the preparation of the plates for the tests was as follows: A circle 12⅝ inches in diameter was drawn concentric with the circumference of the plate, and its included area subdivided into numbered one-inch squares. The thickness of the plate was then determined as follows:

A ⅝-inch "T" bolt, whose end had been ground to a spherical point, was fastened vertically to the table of the small planer in the machine shop. The bridge already mentioned was rigidly clamped in the tool holder, and one of the micrometer-heads inserted and fastened directly above the point of the bolt, being so adjusted that its zero reading was obtained when in contact with the bolt. The plate, whose surfaces were maintained in a horizontal plane, was then inserted between the bolt point and the micrometer, and readings of its thickness at the center of each square were taken and recorded. The mean was obtained of 120 readings, and one-half of the total wear of the point of the bolt was added to it. This gave the mean thickness of the plate. The determination of these thicknesses has been based upon the assumption of a uniform rate of wear of the bolt end. If this is in error, the individual thicknesses will not be appreciably altered, owing to the small extent of the total wear.

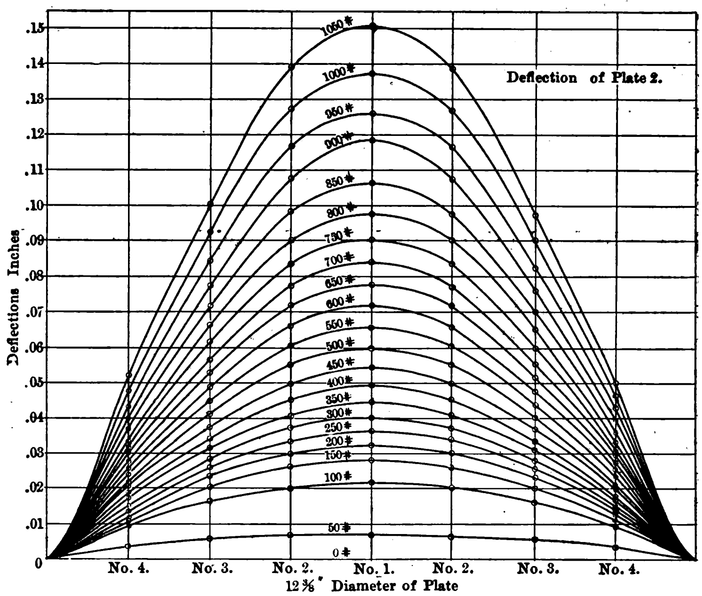
The plate was then painted with white lead, two radial strips at right angles to one another being left uncovered; and the original squares rescribed. The bare strips were left bare, in order to permit the utilization of electrical signaling apparatus, and to facilitate the reliable observation of deflections. These strips lay along axes respectively designated "AA" and "BB."

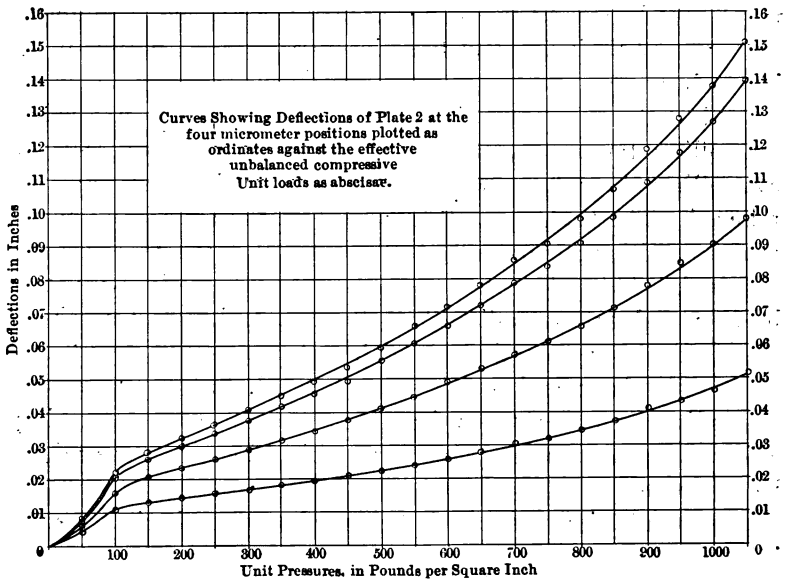
The cylinder having first been filled with water, the plate was then inserted and centered in the apparatus. To insure a tight joint, a gasket of 1-32-inch "Rainbow" sheet-rubber packing was used. In the final test, in order that leakage through the plate might be stopped, this annular gasket was replaced by a disc of the same material, which proved to be entirely efficacious. The nuts were then set up with a sledge hammer, and a three-foot wrought-iron wrench.

The Crosby fluid pressure scale of 1,500 pounds to the square inch capacity was connected to the apparatus through a needle valve by means of 1-16-inch seamless copper tubing; the connection at the instrument was made through a union at the gauge standard. No other use was made of the pressure-regulating device of the instrument than to screw out its plunger to its utmost limit, in order to maintain a sufficient supply of oil in the instrument.

When the bolts were tightened as far as possible, the valve controlling the supply of water was closed, the needle-valve controlling the release was opened, and all internal pressure relieved. The bridge was then placed on the apparatus, in its proper position along one of the axes, and the micrometers adjusted. The electrical connections were made with the bridge; and "zero readings" of the four micrometers taken. The bridge was then shifted to the other axis and new "zero readings" taken; and so, alternately, until three or more sets of readings had been taken for each axis, to insure establishing a fairly accurate datum plane from which the deflections might be observed.

As an additional surety that there was atmospheric pressure in the cylinder when "zero readings" were taken, the small plunger in the pressure scales was pushed down so that the


Deflection of Plate 2.
Deflections Inches
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
1050#
1000#
950#
900#
850#
800#
750#
700#
650#
600#
550#
500#
450#
400#
350#
300#
250#
200#
150#
100#
50#
0#
No. 4.
No. 3.
No. 2.
No. 1.
No. 2.
No. 3.
No. 4.
12⅜″ Diameter of Plate


Curves Showing Deflections of Plate 2 at the
four micrometer positions plotted as
ordinates against the effective
unbalanced compressive
Unit loads as abscissæ.
Deflections in Inches
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
100
200
300
400
500
600
700
800
900
1000
Unit Pressures, in Pounds per Square Inch

point was not in contact with the upper bearing, and the needle-valve between the cylinder and the instrument opened.

The maximum difference in a set of "zero readings" for a given point, occasioned by removing and replacing the bridge, was not more than .0003 inch in any case.

When the "zero readings" had been taken, the needle-valve controlling the release was closed, the valve controlling the water supply opened, the pump started, and pressure gradually applied; in the first test, by increments of 25 pounds per square inch; in the second, by increments of 50 pounds, and in the third test, by increments of 100 pounds per square inch.

The poise on the scale arm was set at the desired point and increasing pressure applied until the arm was lifted. The pump was then stopped, and as the pressure slowly fell off, the point of one of the micrometer-heads was kept continuously in contact with the exposed surface of the plate following it down. At the instant that the scale arm fell, the micrometer reading was observed.

This was done for each point on one axis, the micrometers not in use being screwed up out of the way. Then the bridge was transferred to the other axis, and the same operation repeated. Thus eight observations of deflection were made at seven points on the surface of the plate, the deflection at the center being recorded twice, this being done for each increment of pressure until failure occurred. The pressure at the instant of rupture was noted by observing the gauge reading, and subsequently correcting it by the gauge calibration.

The actual deflections at any point were found by subtracting from the micrometer readings, for the various pressures, the mean "zero reading" for that point and then finding the deflections at the corresponding point on the other axis in the same manner, and ultimately taking the mean of the two values for each pressure as the deflection for that pressure at that distance from the center.

The deflections found in this way were plotted as ordinates against the effective, unbalanced, hydraulic unit pressures acting on the plate as abscissæ, one curve being plotted for each point (curves 1 and 2). From these curves the elastic curve of the plate was plotted for various pressures (curves 3 and 4).

In order to determine the ultimate strengths of the material of the plates, test pieces were prepared from strips cast from the same pour as the plates, and these were tested, respectively, in tension, compressions, and in flexure. The pieces were carefully inspected and measured before being subjected to load.

The elongations of two of the pieces subjected to tension were measured in four inches. Increments of load, in one case of 1,000 pounds and in the other of 2,000 pounds, were taken, and the elongation measured under each load.

For the compression tests, the pieces were placed in the machine between the strips of sheet copper, and load was applied until rupture occurred. No deflections were noted.

In the flexure tests the pressure was concentrated at the middle of the test strip. The deflections were measured by a micrometer-head held in the bridge, which was inverted and supported on the base of the machine. The observations of deflection were taken at a point close to the center, increments of load of 50 pounds were adopted, deflections under each load being recorded, and the breaking loads observed. Stationary supports for the beam were used.

Two more tension pieces were broken by actual weight, the elongation in eight inches being measured by the extensometer after each increment of load.

An examination of the curve showing the deflections of four points on Plate 1 shows a well-marked "yield" point. This occurs at the same pressure at all the points measured and may have been due to the failure of the plate at its edge underneath. The second plate tested (Plate 2) showed a similar crack at its edge, though it does not show any such marked yield point as Plate 1.

The point of "inflection" or zero moment in Plate 1 seems to come between points "3" and "4," as is shown by the plotted elastic curves. In Plate 2 this point occurs outside of point "4." This may have been due to the upward deflection of the ring, which held the plate down and upon which the bridge rested. If this ring deflected, the edge of the plate would not be tangent to a horizontal line. That there was a certain amount of strain in the ring seems evident from the fact that

it failed across a bolt hole, while the third plate was under a pressure of about 1,700 pounds per inch.

The two plates broken (Plates 1 and 2) were .3490 inch and .7175 inch thick, respectively; and the breaking load was 315 pounds per inch on Plate 1, and 1115 pounds per inch on Plate 2, the diameter of each plate being 12⅜ inches. The tests made last winter were only preparatory and are being continued this year with improvements on the apparatus suggested by last year's work.

A REINFORCED CONCRETE OFFICE BUILDING.

BY J. P. H. PERRY, S.B., '03,

JUNIOR MEMBER OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS.

The Eastman Kodak Company now occupy as their headquarters in New York City a reinforced concrete office building located at 235 West 23d Street. This reinforced concrete building is unusual and therefore interesting in that it is used for stores, offices, and lofts and is situated in the heart of the great shopping district of New York. Though there have been a great many buildings constructed of reinforced concrete in all parts of this country, in the East the use of this material has been heretofore reserved for warehouses, factories, power-houses, and various other industrial plants, the problem of giving a sufficiently pleasing finish with concrete to satisfy the prospective tenants and the general public having been considered impracticable of solution. In the Eastman building, however, the architects succeeded in obtaining a structure which, possessing all the admitted virtues of reinforced concrete construction, has also an exterior and interior appearance sufficiently good to excite commendatory remarks from tenants and passers-by rather than criticism. A description of the details of design, construction, and finish of this building makes up this article.

The building was constructed under the supervision and general plans of the architects, and the general contract was let to one of the most prominent firms of builders in New York City. This concern sub-let practically the entire structure to the biggest reinforced concrete company of New York, who designed the building in detail and erected it complete, exclusive of the front wall and the general sub-contracts of lighting, heating, plumbing, elevators, and waterproofing.

The excavation was prepared ready for foundations under the direction of the general contractor. Owing to several delays it was Sept. 6 before the Turner Construction Company was able to begin the erection of the building.

The general plans and specifications called for an eight-story and basement structure, 60 feet by 90 feet in plan, with reinforced concrete walls, wall columns, floors, stairs, partitions, curtain walls, roof, parapet, and roof houses, together with a vault under the sidewalk. The interior columns, owing to the very conservative Manhattan building laws and the necessity of obtaining all the floor space possible, were made of hollow cast iron, circular in section, and were filled with concrete and covered with a three-inch fireproof protection of reinforced concrete. The front of the building, shown in Fig. 1, was of ornamental terra-cotta tile, of a dull Portland gray color, which matches the concrete walls so evenly as to make the general public wonder at the remarkably smooth and beautiful finish obtained with concrete. In Fig. 1 the concrete walls appearing at the top of the building had not, at the time this photograph was taken, received their coat of La Farge cement paint; hence the contrast in color with the front. The general layout of the building shows in Figs. 4 and 5.

The cast-iron columns are worthy of study in the unique and efficient means provided for bonding the concrete beams and girders to them at the floor levels. In Fig. 3 the top of the columns can be seen. The hollow elongated head runs up above the floor level and is machine finished and bored to allow for bolt connections with the column in the succeeding story. The beam and girder bars, as noticed in Fig. 3, run through the slots, and the entire hollow column is filled with concrete, making a perfect bond with the floor, and in a measure stiffening the column as well as fireproofing it.

The front details of the building were worked out in steel, as shown in Fig. 2. This was determined by the special layout required on the first or street floor. The long front show window and the narrow doorways on either side connecting with the stairways and passenger and freight elevators made a span of thirty-five feet necessary. The high windows, as compared to the story heights, made a concrete girder of proper depth impracticable. Heavy steel "I" beams were substituted at the second floor level, and above this steel plate girders for all the upper floors, except at the roof level. The special layout held only on the first floor, but to have made the front girder of

concrete for the upper stories would have necessitated the carrying up of two concrete columns, — being the prolongation of the two interior rows of columns, seen in Fig. 6, — and the consequent introduction of a very heavy girder at the lower floor level, as this girder would be in direct shear with a seven-story load to sustain. The roof girder was built of concrete, as there was plenty of head room in the eighth story.

FIG. 1.

The floors were designed to carry the following loads: The first floor, 300 pounds per square foot; second, third, fourth, and fifth floors, 200 pounds; sixth floor, 250 pounds; seventh and eighth floors, 200 pounds, and roof, 50 pounds. The resulting construction complies with the Manhattan building laws, which allow the reinforcement to be figured at a unit stress of

16,000 pounds per square inch, and the concrete at 500 pounds per square inch, with the use of the straight-line formula. The reinforced concrete columns were calculated according to the Building Department's formula, which is very conservative as compared with almost universal modern practice.

The reinforcement consisted of Ransome cold twisted bars and was placed according to the regular Turner Construction Company system. The general appearance of the reinforcement when placed and ready for concreting is seen in Fig. 4. The beam and girder bars were of large size twisted steel, running from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inches square. The slab bars were 5-16 inch or $\frac{3}{8}$ inch, depending upon the loading, with $\frac{3}{8}$ inch or $\frac{1}{2}$ inch transverse distributing bars. The beams and girders had stirrups — shear members — of 5-16 inch or $\frac{3}{8}$ inch bars placed where required. These stirrups may be seen by careful scrutiny near the ends of the beams in Figs. 3 and 4. The slab reinforcement was all securely wired together by tying the tension bars with No. 18 annealed wire to the distributing bars — notice in Fig. 3 — and was held up from the forms where crossing the beams by the insertion of "Z" irons. These "Z" irons were bent by hand from No. 26 gage black iron cut into strips of the proper dimensions. The columns were reinforced with vertical twisted bars and hoops securely tied at regular intervals, varying according to the loads. Some of these hoop columns can be seen at the left of Fig. 3.

The concrete used throughout the building was mixed 1-2-4 — cement, sand, and trap rock — and was placed wet, — the consistency being comparable to molasses, — no tamping being necessary other than gentle puddling in the walls and columns and a general hammering of the forms and joggling of the reinforcement to secure a smooth finish and proper imbedding of the steel.

The forms were designed according to the Turner Construction Company's regular standard and were uniformly tight and strong and possessed a great advantage in their simplicity with regard to erection and removal. A general idea of their character for the floors can be obtained from Figs. 3 and 5 and for the columns in Fig. 2, at the top of the structure. The material was North Carolina pine for the small boards, and spruce

for heavy members, such as 4 inches by 4 inches, and 2 inches by 8 inches. All forms were painted, to prevent sticking of the concrete to them, and to preserve them, with a very liquid mixture of kerosene oil and petrolatum, — a crude and very cheap form of vaseline. Immediately upon removal from the concrete the forms were scraped and thoroughly cleaned, and

FIG. 2.

then given a heavy coat of "grease," as the mixture just described was termed. Generally before the reinforcement was placed the forms received another "greasing."

The sub-contract held by the concrete company was a penalty and bonus one, giving a total of 110 working days for the completion of all the reinforced concrete work in connection with the building. Work was started on the footings — which

were of the usual spread type, reinforced with a grillage of heavy Ransome bars — on Sept. 6 and prosecuted with great speed until winter weather interfered in December. The progress after the first floor was in place was at the rate of a story a week. In one instance a floor was concreted in 4½ days after the completion of the floor below it. The entire reinforced concrete work was finished in 109 working days, and the building was turned over by the general contractor to the owners on April 1.

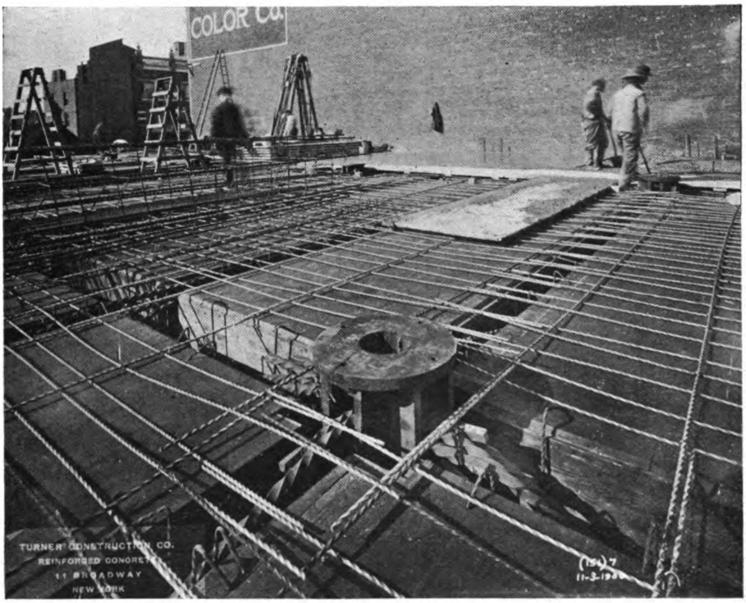


FIG. 3.

The method of construction was "skeleton," the columns and floors being carried up similar to steel cage buildings, the walls and partitions following afterward. The forms were erected for one-half the floor; then while the carpenter gang was completing erecting the forms for the remainder of the floor, the steel men would be placing reinforcement as fast as possible, and the speed of the two gangs was such that the carpenters would generally only just get out of the way of the steel men in time. While the steel was being placed in the

last part of the floor, the concrete foreman would be coming along with his gang, filling the columns and concreting a part of the floor where the steel already was in place. These conditions may be clearly appreciated by studying Fig. 3. At the extreme left of the photograph carpenters can be noticed at work at the front of the building, while the steel men are near them, and at the right of the picture the concrete is being poured. While the concrete was being placed in the whole floor (see Fig. 4), the steel gang would be bending and sorting steel, ready for the next floor, and the carpenter force working on assembling the forms which had been taken down from some floor below by the form-wrecking gang. The concrete was received from the mixer by means of a tower hoist and wheeled in Ransome carts to the place wanted on the floor. Panel runs carried the carts over the reinforcement (notice Fig. 4). The columns were generally concreted a half a day in advance of the floor to allow for settlement and to do away with possible shrinkage cracks. Fig. 3 shows the columns being filled in accordance with this practice.

As soon as the concrete in the newly laid floor was sufficiently set to allow walking upon, — generally one day, — the carpenter force would start erecting column forms which had been hoisted up by the form-wrecking gang as fast as the carpenter foreman desired them. As soon as two column forms were in place and temporarily braced, a girder box was set on their top, and in successive operations other columns were erected, girders set, beams placed between the girders, and slab panels set on spreaders between the beam boxes. It took on an average of 3½ days to erect a floor ready for placing steel. The reinforcement was ready one day later, and the floor concreted by the end of the week.

The handling of materials and the mixing and hoisting of the concrete was carried on by means of a carefully laid out and efficient plant, which consisted of a No. 2 Ransome mixer operated by a twelve-horse-power motor, run from the Edison power mains in 23d Street, and a Ransome concrete bucket and hoist operated by a Ledgerwood hoist. This mixing plant was located at the rear of the building. Sand and stone were dumped at the front of the building from the street into the

basement and were wheeled back to storage piles near the mixing plant. Cement was carried from the wagons on to the first or street floor and sent down chutes to be piled in the basement in separate lots, which were designated according to the carload shipments received from the cement mills, so that, in case of unfavorable test reports, each carload of cement could be identified. Water came from a hose connection with the house line from the street. Steel was received on the first floor and bent there until the third floor was clear of forms, when, in order to avoid interference with the receipt of all the material for the sub-contractors on the ground floor, the bending table and all the steel stock was removed to the second floor.

There were two complete sets of floor forms made for this building, the column forms being considered as a part of the floor forms. These column forms, in good setting weather, were removed about four days after the concrete had been placed, and the floor forms — beams, girders, and slabs — in about six days. The beams and girders were posted up (see Fig. 2) before final removal of the supporting forms, and these posts, consisting of 4 inches by 4 inches, with a cross piece nailed to the top, were wedged up hard to a bearing and generally spaced about 5 feet C.C. These supports were left in place about three weeks, except in winter weather, when six weeks was generally allowed to elapse before removal.

The forms for the walls consisted of $\frac{7}{8}$ inch N.C. tongued and grooved boards made into panels with 3-inch by 4-inch studding placed about 2 feet C.C. and bolted together with $\frac{3}{4}$-inch bolts spaced about 2 feet C.C. both ways. The two sides of the walls were kept apart by wooden spreaders, which were knocked out as the concrete was put in. The bolts were protected by light black iron sleeves and were pulled out after about twenty-four hours' setting in good weather. The holes left by the bolts and sleeves were pointed up upon removal of the forms, which generally occurred about forty-eight hours after concreting. The partition forms were similar to those for the walls and were left up about the same time.

The concrete poured into the walls and partitions was a wet mixture and was carefully puddled. Where 12-inch walls were concreted, it was not very difficult to obtain a good finish,

but in filling 4-inch partitions great care in mixing and depositing the material had to be exercised to avoid rough spots.

The wall and partition reinforcement consisted of $\frac{3}{8}$-inch bars spaced 18 inches horizontally and 24 inches vertically, and were bonded into the wall columns by means of lapping and tying to bond bars left sticking out of the columns when they were filled. This reinforcement was placed as near the center of the walls as possible.

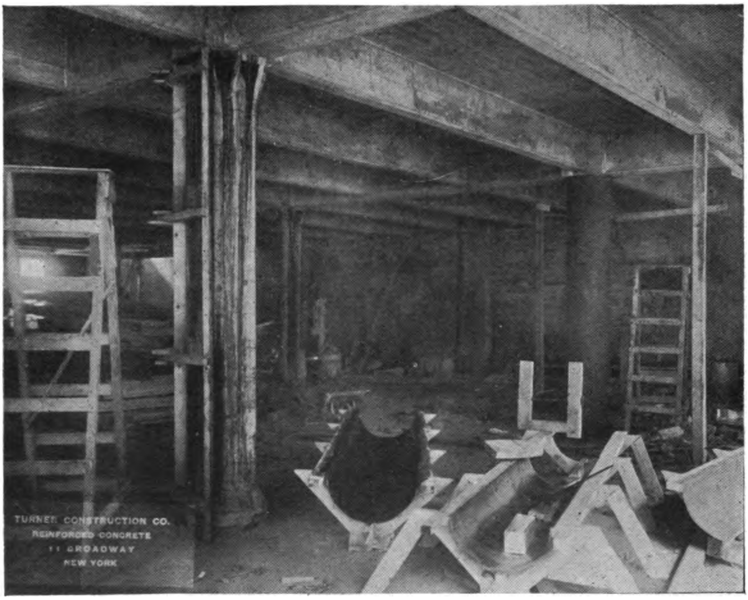


FIG. 5.

The fireproofing of the cast-iron columns was handled very simply and effectively. The specifications called for a 3-inch protection of rock concrete, reinforced by four $\frac{1}{4}$-inch round bars, standing away from the cast iron $1\frac{1}{2}$ inches, and wrapped spirally with No. 12 galvanized-iron wire. This reinforcement shows clearly in Fig. 5. The forms used also show in this figure, and little explanation is necessary. The metal lining was No. 20 sheet iron nailed to the wooden ribs, which were sawed out of 2 inches by 8 inches and were spaced 3 feet C.C. To fill these forms small chutes were made at the top, on either

side, of the column, and the concrete handed up in pails and poured in. Two men with wooden blocks constantly hammered the metal form to produce a smooth surface. How well they succeeded is seen in the column at the right of Fig. 5. The concrete was a molasses-like mixture of $\frac{1}{4}$-inch rock, sand, and cement, in proportion 2-2-1, mixed on the floor near the column in just sufficient quantity to fill the column. Ornamental bases (see Fig. 6) of cement mortar were afterwards placed about the columns by erecting a form and bracing it from the ceiling so as to render it immovable, and placing the mortar in it and running the molding with a cement mason's tool.

The stairs were of reinforced concrete protected by American mason safety treads. The thickness of the main supporting slab under the toe of the riser was 5 inches minimum, and the reinforcement consisted of $\frac{3}{8}$-inch tension bars and $\frac{1}{2}$-inch distributing bars. In constructing the stairs, forms for two flights were erected in each stairwell, and all four stories of stairs thus made ready were concreted at once. The next morning the finish was mixed and placed and troweled to a surface. Two good masons and two helpers would do the four-stair runs in a short day with finish $\frac{3}{4}$ inch thick. Forms were left under the stairs at least two weeks, as there was constant traffic over them.

The finish of the floors was a cinder fill, over which, on some floors, was spread a 1-inch mortar finish, which was troweled to a surface, and on the other floors a maple floor was nailed to 3 by 4 sleepers embedded in the cinder fill. The plumbing and heating pipes and lighting ducts and risers were run through openings, boxed out in the floors and partitions by means of either wooden or tin sleeves or boxes nailed to the forms before the concrete was placed. The elevators were put in shafts which had been carried up plumb throughout their length, and all the ironwork, such as guides, bearing beams, and sheeve blocks, were set by the elevator sub-contractor. The windows were all wire glass set in Veightman metal frames, which were set in the wall forms before concreting and securely braced to prevent bulging under the pressure of the wet concrete.

The roof was unusually high above the eighth floor, being 18 feet at a maximum, and sloping for drainage purposes to a minimum of 16 feet. This height was necessary to allow for a hanging ceiling and air space in the eighth story. This height made splicing of the 4-inch by 4-inch supports necessary, and the placing of extra sway and buck bracing between them requisite, which, coupled with special front and rear beam construction, occasioned some delay in getting ready for concreting and made the expense run very high. The rear beam just referred to was 7 feet deep, combining a beam and a rear curtain wall, and had to have special forms and supports. The placing of steel in this deep narrow box — the girder was only 12 inches thick — was a slow job, though fortunately the reinforcement was light. The front roof beam, or girder, as it may more probably be called, was of a unique design. Besides having to carry its proportionate share of the roof slab, it furnished support for a very heavy terra-cotta tile cornice built around steel brackets. This cornice may be seen in Fig. 1. The girder was 5 feet 6 inches deep and 8 inches thick, with a series of 6-inch brackets on the front to furnish support for the steel cornice brackets. The reinforcement in this girder was complicated and heavy and cost as much to place as did the steel in all the rest of the roof.

The precautions taken to protect the concrete against winter weather were simple, though in the end, owing to the length of time in which winter operations were pursued, expensive. Before the temperature dropped below freezing sufficiently to warrant attention, the floors had all been concreted, and the roof was put in in late November, during a couple of warm days. The cold weather ensuing immediately, salamanders — big open circular stoves, one of which may be seen at the extreme right of Fig. 5 — were hung up under the roof forms, and coke fires kept going day and night for a week until the concrete was well hardened. During December, January, and February the upper-story walls, most of the partitions, and all the stairs were built, and the concrete which was put in during freezing weather was heated by salamanders for at least two days and two nights. The forms on vertical work were generally removed in three days. In heating walls or partitions

burlap lean-tos were built by placing scantling against the walls, and the salamanders put inside of these shelters and spaced about 10 feet apart. Where the partitions made enclosures, such as in the elevator and stair-walls, or in the toilet rooms, the salamanders were placed inside the little rooms thus made. Concrete was never put in when the thermometer was below 18° F., and at as low a temperature as this only when good heating was possible, and never in work which had to support anything above it. In load-supporting work, such as stairs,

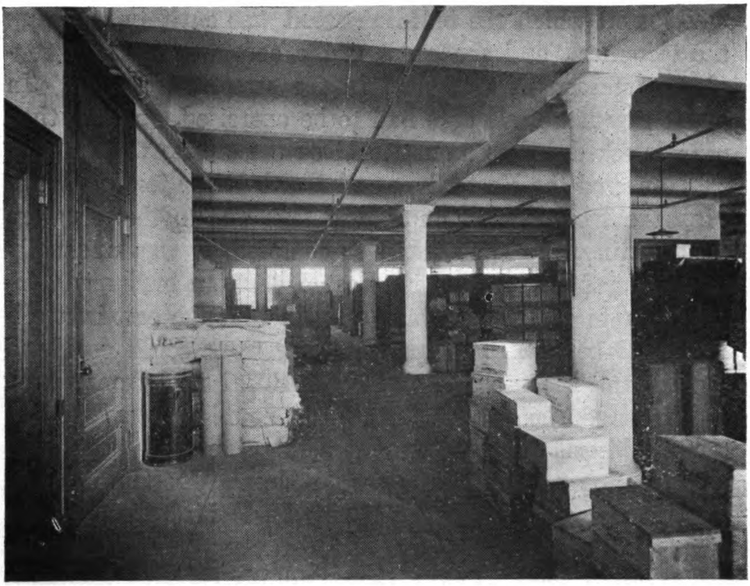


FIG. 6.

roof house roofs, and the like, the minimum concreting temperature was 24°. Some partitions and several of the fireproofing protections around the cast-iron columns were severely frozen and the forms taken down within twenty-four hours, while the concrete was still hard with frost. The gradual thawing of this frozen concrete did not seem to render the vertical masses weak enough to collapse, probably owing to the reinforcement holding the concrete in place and the care taken to prevent jarring or knocking until thoroughly thawed out and

set. Of course, such proceedings as this were allowed only when the concrete in question had absolutely no chance of ever having any load to carry, and were allowed at all only because of the imperative need of keeping ahead of the painter's men. At the time the first trial of removing the forms from frozen fireproofing was made, steam was being turned on in the building, and the thawing of the concrete was certain to be uniform. No ill effects have been discovered. The building has been in use almost a year, and the concrete under discussion is as hard and of as good appearance as any in the structure.

The lot on which the building stood was entirely taken up by the structure, and the great traffic across 23d Street rendered any storage of materials in the street impossible. In receiving raw materials care had to be exercised, and the time of arrivals scheduled so as not to block the cross-town car line, which connected the East River and North River ferries. Considering the winter work and the delays due to the situation of the building, the time taken to complete it was unusually short. The job was more complicated than an ordinary reinforced concrete factory or warehouse in that the cast-iron columns had to be erected before the floor work could go ahead full speed, and because also of the structural steel front which had to be placed before the floor forms could be completed.

The architects who drew the general plans and supervised the construction of the building were Messrs. McKim, Meade, & White. The general contractor was M. Reid & Co., and the Turner Construction Company, 11 Broadway, did all the reinforced concrete work. Mr. Cairns and Mr. W. T. Anderson were the architects' representatives, while Mr. McDonald of M. Reid & Co. had general charge of the sub-contractors. Mr. T. A. Smith and the writer were respectively superintendent and assistant superintendent for the Turner Construction Company, in charge of all the concrete work.

SOME PILE-DRIVING EXPERIMENTS IN CONNECTION WITH THE CONSTRUCTION OF THE CHARLES RIVER DAM.

BY J. ALBERT HOLMES, C.E.,

DIVISION ENGINEER, CHARLES RIVER BASIN COMMISSION.

There appeared in the January number of the JOURNAL a résumé of the work being done by the Charles River Basin Commission at Craigie's Bridge and along the Boston and Cambridge shores of the proposed basin.

The author tells us that the project of building a dam across the Charles has been discussed since 1859; it might be remarked, as a matter of interesting historical information, that it was proposed in 1814 to construct a dam across the river from a point near the Cambridge end of the Harvard Bridge to the vicinity of Sewell's Point in Boston. This project is shown on an ancient lithograph, a copy of which may be found in the Harvard Library, shelf number M 3410.10.

As to the present condition of the work, the concrete structures within the Boston coffer-dam — namely, the lock and a portion of the Boston marginal conduit — are practically completed; the draw-bridge over the lower end of the lock is substantially finished. In the Cambridge coffer-dam the sluices are also practically completed, and the sluice and tide gates, for controlling the flow of the river, in place; also the gates in the small boat lock. The large gates in the lock are being erected.

Including the portion in the Boston coffer-dam, 3,500 linear feet of the Boston marginal conduit is finished, 800 linear feet of embankment wall built above Cambridge Bridge, and a portion of the filling placed along about three-fourths the length of the embankment, which extends to the Fens above Harvard Bridge.

The work of building the Cambridge marginal conduit has begun on the Cambridge shore.

Up to Jan. 1, 1907, 9,969 foundation piles had been driven in the Boston and Cambridge coffer-dams, amounting to 297,000

linear feet. The average length of the piles under the lock after cutting off was 29 feet; under the sluices, 31 feet 4 inches. The specifications called for piles to be winter-cut from straight, live trees, not less than ten inches in diameter at the butt when cut off in the work, and not less than 6 inches in diameter at the small end.

A safe load of 12 tons per pile was assumed for the lock foundations and 7 tons per pile at the sluices.

The Wellington or *Engineering News* formula was used in determining the bearing power of the piles. This formula is described by the *Engineering News* as follows:

$$L = \frac{2\,wh}{s + 1}$$

"In which L is the safe load in tons (using a factor of safety of 6); w is the weight of the hammer in tons; h is the fall of the hammer in feet, and s is the penetration or 'set' of the pile in inches, under the last blow of a free-falling hammer (not retarded by hammer rope) striking a pile having a sound head. If a friction clutch driver is used, so that the hammer is retarded by the rope attached to it, the penetration of the pile is commonly assumed to be just one-half what it would have been had no rope been attached, that is free falling. There have been too few experiments made to warrant any great reliance upon this last assumption."

The above formula is discussed by Foster Crowell, a member of the American Society of Civil Engineers, in the *Transactions* of that society for December, 1899, Vol. XLII, page 278, as follows:

"What enables the descending ram to drive the pile is the energy stored therein, but not all of that energy is available for the purpose, half of it being required to maintain the movement of the ram. That which is available is known as the accumulated work, to be expended upon the sum of the resistances offered by the pile.

"In the Wellington formula the principle of accumulated work is the basis; it is expressed in inch pounds, but as it contains a silent factor of safety of 6, and as for convenience h is given in feet, the accumulated work is written 2 wh instead

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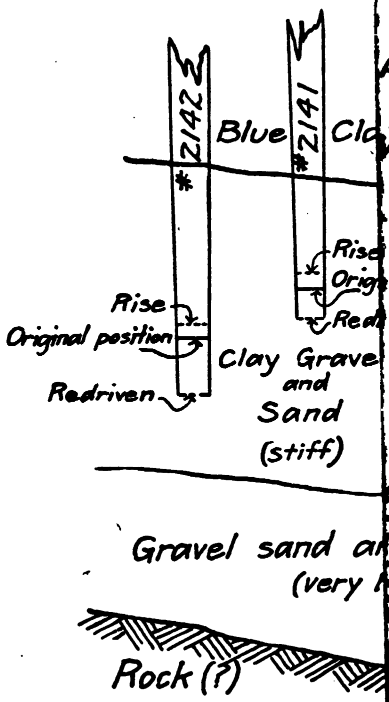

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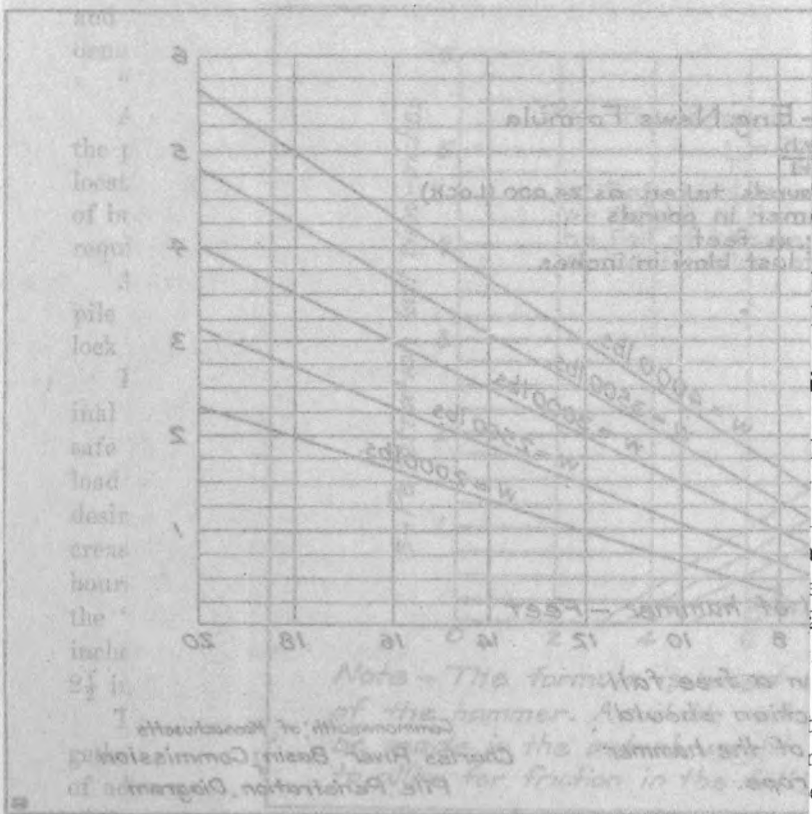

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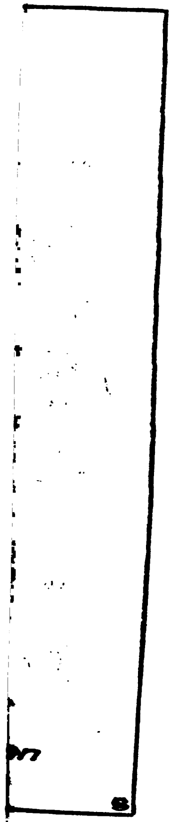


Fig. 1

Fig. 2

of w 12 h. The denominator is the measure of resistance developed by the pile, as indicated by its penetration under the last blow, or settlement, s, also expressed in inch terms.

"Were it not for the presence of resistances in the pile-driving machine, and other causes tending to oppose the driving of the pile, s would be the full measure of the net resistance, and the quotient would be that resistance; but these various unmeasured opposing forces must be taken into consideration, and they are represented by the constant quantity, 1, in the denominator.

"Thus we have the derivation of the Wellington formula."

A diagram (Fig. 1), based on this formula, was furnished the pile-driving inspectors as a guide, and a record kept of the location, kind, length, and diameter of each pile, also elevation of butt as left, time consumed in driving, and number of blows required to drive last foot, and total penetration of pile.

A number of experiments were made in connection with the pile driving, one of which was the redriving of a pile in the lock foundation after a rest of fourteen and one-half hours.

The "set" (s) of this pile under the last blow of the original driving was four inches. This gave, using the formula, a safe load (L) of only 13,400 pounds, which was about half the load the piles under the lock were assumed to carry. It was desired to learn how much the bearing power of the pile increased after driving; after a rest of fourteen and one-half hours, the pile was redriven through a distance of 11¾ inches, the "set" (s) under the first blow of the redriving was 2¼ inches, giving for L 20,600 pounds; under the last blow s was 2½ inches, giving for L 19,100 pounds.

The piles under the lock walls were driven very close together, and as a result many of them rose during the driving of adjacent piles. Careful elevations were taken on a number of the first piles driven in a thickly piled area during the driving of the remainder of the piles, and four of the original piles which had risen redriven. The results of this redriving are given in the table (Fig. 2).

The inspectors' data gives for the first pile in the table, $L = 22{,}000$ pounds for the original driving. The pile had been

driven a little over a month and had risen .27 feet; the first blow of the redriving gave for L 26,000 pounds, and the last 23,000 pounds.

During the redriving of these four piles the "set" was carefully measured for each blow, the fall of the hammer being uniformly ten feet.

The last pile (No. 2142) acted in a peculiar manner during the latter part of the redriving. It will be noticed that the "set" (s) for the first blow was $1\frac{3}{4}$ inches, and L 25,000 pounds, while the last blow gave $3\frac{1}{2}$ inches "set" and L only 12,000 pounds, the spacing, center to center of piles, was 2 feet by 2 feet 6 inches.

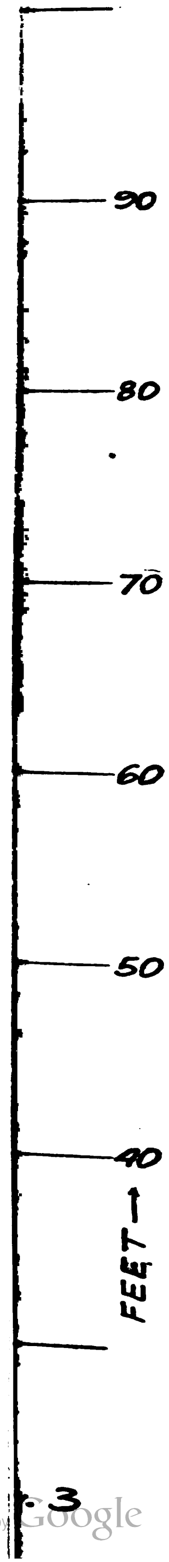
Another experiment was made to determine whether or not a pile that had been driven for the lock foundation and had risen would settle back into its original position when loaded; the pile had been in the ground about one month and had risen .14 feet during the driving of adjacent piles.

The inspectors' data gave 26,000 pounds for L as originally driven. The pile was capped, a timber platform bolted to the caps, and a load consisting of pig lead gradually applied.

During a period of seventeen hours a load of 9,400 pounds produced no settlement; the load was increased to 17,400 pounds, and at the end of another period of twenty-four hours a settlement of .006 feet had taken place. The full load of 30,400 pounds was then applied, and at the end of the next twenty-four hours the total settlement amounted to .015 feet, which gradually increased to .029 feet, ten days after the first load was applied; this amount did not increase up to twenty-five days, at which time the whole load was removed and the pile found to have returned to the position it was in when the first load was put on.

At the sluices in the Cambridge coffer-dam eight test piles were driven in pairs, the piles in each pair being about three feet apart. The diagram (Fig. 3) shows the action of the piles in one pair while being driven.

The geology of the river bottom through which the piles passed is given. The heavy line indicates the movement of the tip of the pile, and the resistance to driving is shown as it passes through the different strata; the length of the light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vertical lines show the fall of the hammer, and the number of lines the number of blows. The kind and dimensions of the piles are given, the weight of hammer and follower (the piles were driven from a floating machine, and a follower used while redriving), also the actual driving and redriving time and the elapsed or total time consumed.

To obtain these data a party of five men was required. A scale was marked on the gins of the pile driver, and a tide gage set in a convenient position. One man called the reading on the scale at the beginning of the fall of the hammer; a second called the reading at the end of the fall, which also gave the elevation of the butt of the pile, from which that of the tip was determined; a third man recorded the readings of the first two; a fourth man was engaged with a stop-watch in keeping the actual driving time, while the fifth kept the total time, noted the rise or fall of the tide, the vertical movement of the scow, and checked the total movements.

It will be noticed that pile No. 5007 of this pair was redriven after a rest of only three hours, and that the tip finally reached an elevation only a little below that of the other pile in its original driving. While none of the eight piles refused to start under the first blows of the redriving, a sharp break occurs in the diagram at the point where the redriving began.

The following table shows the influence penetration has on the resistance to starting, due to additional surface under friction:

Pile Number	Period of rest hours	Number of blows 1st 6″ of re-driving	Penetration at beginning of redriving
5008-3	3	3	18′
5007-2	3	2	24′
5006-1	3¾	4	24′
5005-4	172	6	32′
5001-1	142½	10	33′
5003-3	141	10	34′
5002-2	213¼	13	34′
5004-4	172¾	13	39′

The first six inches of redriving corresponds to the nearly horizontal portion of the heavy line of the diagram and includes the number of blows shown in the table.

Penetration seems to have influenced the resistance to redriving more than the time the piles were allowed to rest.

As above mentioned, the piles were driven in pairs, and all within an area 50 feet by 80 feet; the pairs are indicated by the figure following the pile number. In driving, pairs showed the same characteristics while passing through similar strata.

The writer does not attempt to draw conclusions or formulate a theory. The simple facts are given and the results stated, but it is thought that much may be learned by a careful study of the data.

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A QUARTERLY

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY.

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.

Subscription Rates.

Per year, in advance	$1.00
Single copies	.35

Address all communications:—
HARVARD ENGINEERING JOURNAL,
Room 218, Pierce Hall,
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.

EDITORIAL.

We would call special attention to the first article in this issue — that on the New York Subway, by Mr. Stephen U. Hopkins, '97. This construction is especially interesting to readers of the JOURNAL, as there are employed upon the work a large number of Harvard graduates, including Mr. George S. Rice, Chief Engineer. The first installment, printed in this issue, is largely historical, and, in a general way, descriptive. The second, to be published in the January issue, will describe special construction and methods of work.

Mr. Hopkins wishes us to state that he will be glad to answer any questions concerning his article, through the col-

umns of the JOURNAL, and we hope our readers will avail themselves of this opportunity. Credit is due Mr. Pierre P. Pullis, New York, for the excellent photographs of parts of the work.

HARVARD ENGINEERING SOCIETY.

The society began its thirteenth year on Wednesday, Oct. 9, when its first meeting was held in the Assembly Room of the Union. Prof. I. N. Hollis spoke informally on some of his experiences as a marine engineer, and Prof. L. S. Marks on technical schools in Germany. The first meeting was very well attended, 110 men being present, and the prospects for a successful year are good. The starting membership is 96, which will undoubtedly be considerably increased. At the next meeting, on Nov. 13, there will be an illustrated talk by Franklin Remington, '87, president of the Foundation Company of New York, on the present practice of foundations for sky-scrapers in New York City.

An interesting list of speakers is assured for the rest of the year, as the Harvard Engineering Society, recently formed in New York, has promised to coöperate with the undergraduate society in securing graduates who are engaged in engineering work as speakers. Mr. H. A. Carson, chief engineer of the Boston Transit Commission, and J. R. Worcester have also promised to speak.

For the benefit of graduates it may be well to mention the annual dinner of the society, which will be held the latter part of February, probably on a Saturday, as it was last year. This evening proved convenient for graduates, and last year 145 men attended the dinner.

The committee, which was appointed by Professor Hollis, in accordance with a motion passed at that dinner, to investigate ways in which a closer union might be effected between the Engineering Department of Harvard and the graduates engaged in engineering work, met in New York on Nov. 1. The Executive Committee of the Harvard Engineering Society of New York met with them, and the Engineering Department was represented by Professor Johnson. The following men

were present: G. S. Rice, Franklin Remington, H. M. Hale, S. U. Hopkins, J. R. Worcester, A. C. Jackson, B. B. Thayer, Francis Mason, J. F. Sanborn, F. L. Gilman, and L. J. Johnson. The meeting was most successful, and one from which results may be expected.

CIVIL ENGINEERING CLUB.

The Civil Engineering Club has bright prospects for a very successful year. Our plans call for at least one meeting each month, addressed by some man of prominence in engineering circles. As engagements are uncertain at the best, any announcement at this time of future speakers would be decidedly premature.

Our first meeting this year was addressed by Prof. L. J. Johnson and Mr. Wisner Martin. Professor Johnson gave us a few incisive words of good advice and introduced Mr. Wisner Martin, who talked to us in an interesting manner about the construction work now almost completed at the addition to the Harvard Power Station of the Boston Elevated Company. The vacancies existing in the offices of Secretary and Treasurer were filled by the election of C. T. Brady, Jr., and F. T. James respectively.

Our present membership numbers about twenty-five, most of whom are seniors. We want every man who is interested in civil engineering to join us, for the future of the club depends on the under-classmen. The annual due is the nominal one of $1.00, and a shingle is bestowed gratis.

The officers are ready to do their utmost to make this year a success, and they are certain that every member of the club is doing his best to accomplish the same end.

THE MECHANICAL CLUB.

The total membership of the club is between forty and fifty, of whom about thirty are active members. The average attendance at the monthly meetings is about twenty.

The first meeting of the year was held on Oct. 30. Mr. Kennedy of the Edison Electric Light Company was to have

spoken on "The Practical Management of a Steam Turbine Plant," referring to the L Street Station in South Boston for illustrations. He was detained by an accident to the machinery, but will doubtless speak later on. Professors Hollis and Marks spoke in his place. Professor Marks told of some of the early facts concerning the introduction of the steam engine and gave some of the incidents of his trip abroad last year. Professor Hollis spoke of some of the early and still common ideas about steam expansion, illustrating by the experiences of the United States steamship *Pensacola* and by very interesting personal experiences aboard the *Dolphin*.

It has been proposed to have some of the members of the club give the papers at a few of the later meetings.

MINING CLUB.

The first regular meeting of the Harvard Mining Club was held in the Union on Thursday, Oct. 31. Professor Sauveur of the department gave a short but interesting lecture on "Metallurgy as a Profession."

The club hopes to make this a banner year by securing speakers who will interest not only those in the Department of Mining and Metallurgy, but other members of the University as well. Professors Smythe, Peters, Sauveur, Raymer, and White, and several practicing engineers, will probably address the club in the near future. Meetings are held every two weeks.

GRADUATE NOTES.

Class of 1907.

Civil Engineers.

Chester B. Lewis, A.B., S.B., is chainman on the East River Tunnel of the Pennsylvania, New York, & Long Island Railroad, engaged in office and field work in the New York or Long Island City sections of the tunnel or its approaches. 113 Monument Place, Indianapolis, Ind.

RAYMOND SICHLES, S.B., is inspector on the construction work of the Pennsylvania, New York, & Long Island Railroad in New York City. 665 Madison Avenue, Elizabeth, N. J.

R. K. TOMLIN, S.B., was with the Pennsylvania, New York, & Long Island Railroad, working in the East River Tunnel until the middle of August. He is now rodman on the Board of Additional Water Supply of New York City at Poughkeepsie. Board of Additional Water Supply for New York City, Poughkeepsie, N. Y.

GEORGE E. DOYEN, S.B., has been a foreman for the Hastings Pavement Company, putting in asphalt block pavements in New Brighton, S. I., also doing office work and on the reports. He is to be in Cambridge this winter as assistant to Professor Love, also doing graduate work. 38 College House, Cambridge, Mass.

CLARK R. MANDIGO, A.B., M.C.E., is building inspector for the Northern Pacific Railroad, and at present is engaged in inspecting a steel and concrete viaduct, 150 feet high and 2,800 feet long, at Valley City, N. Dak. 799 Iglehart Avenue, St. Paul, Minn.

JOHN VASSAR STARK, S.B., is a draughtsman for the New York Central & Hudson River Railroad, Electrification Department, in New York City. 108 Stark Avenue, Penn Yan, N. Y.

CHARLES J. O'DONNELL, S.B., has been with the Charles River Basin Commission during the summer. Care of Charles River Basin Commission, 12 Bridge Street, East Cambridge, Mass.

CHARLES A. SARGENT, S.B., is rodman for the Additional Water Supply of New York City. He is at present at work in Staten Island. 7 Anderson Avenue, Port Richmond, S. I., N. Y.

HOWARD M. TURNER, A.B., S.B., is with the Turner Construction Company, New York City. For two months he was inspector on a ten-story reinforced concrete warehouse in Jersey City, and at present is in the Estimating Department. 31 West 45th Street, New York, N. Y.

PRIMITIVO PORTAL is rumored to be engaged in building roads in Cuba.

Electrical Engineers.

Henry Lewis Lincoln, A.B., S.B., is with the General Electric Company in Schenectady, N. Y. He is at present in the testing department of heavy electrical machinery. 5 State Street, Schenectady, N. Y.

Gugy A. Irving, S.B., is an apprentice with the Westinghouse Electric Manufacturing Company at Wilkinsburg, Pa. 756 Hill Avenue, Wilkinsburg, Pa.

Edward M. Farnsworth, A.B., S.B., is with Stone & Webster, Boston, Statistics Department. During the summer he was in the Auditing Department. Care of Stone & Webster, 147 Milk Street, Boston, Mass.

Quincy A. Brackett, A.B., S.B., is with the Western Electric Company as student apprentice in New York City. Western Electric Company, New York, N. Y.

Walter K. Cabot, S.B., is with the Western Electric Company in New York City. 530 West 124th Street, New York, N. Y.

Richard H. Harris, A.B., S.B., is with Stone & Webster, Boston. 15 Winter Street, Salem, Mass.

J. V. Quinlan, S.B., is with the Hudson River Telephone Company at Newburgh, N. Y. 52 High Street, Brookline, Mass.

J. S. B. Sullivan, S.B., is in the Electrical Engineering Department of the General Electric Company's works at Lynn, Mass. 7 Vine Street, Lynn, Mass.

Robert D. Thomson, during the summer, has been shop plant engineer with the General Electric Company at Lynn, Mass. He is to be an assistant in the Department of Engineering at Cambridge during the winter. 19 Weld, Cambridge, Mass.

Charles J. Mundo, S.B., is taking the student course at the General Electric Company's Lynn works. 7 Vine Street, Lynn, Mass.

Irving B. Hitchings is also taking the student course at the General Electric Company's Lynn works. 48 Chestnut Street, East Saugus, Mass.

Thomas J. Hanlon is with Stone & Webster, Boston.

Mechanical Engineers.

William Morris Davis, II, is a draughtsman with Curtis & Huse, Colorado Springs. 1117 North Nevada Avenue, Colorado Springs, Col.

Frederic Arthur Alden, A.B., S.B., was with the Charles River Basin Commission as rodman during the first part of the summer. Gorham Street, Cambridge, Mass.

Harry P. Forte, S.B., was instructor in statics, kinematics, and resistance of materials at the Harvard Engineering Camp during the summer. He is to be Austin teaching fellow in applied mechanics during the winter. He is also doing graduate work in the Department of Engineering. 13 Stoughton, Cambridge, Mass.

Willard C. Brinton, S.B., is with the Westinghouse Electrical and Manufacturing Company at East Pittsburg, Pa. He is at present investigating improvements in the office and shop organization. 512 Franklin Avenue, Williamsburg, Pa.

Edwin F. Burnham, S.B., is with the Dennison Manufacturing Company, Framingham, Mass. 18 Myrtle Street, Waltham, Mass.

F. Rodney Pleasanton, A.B., S.B., is an Austin teaching fellow in the Department of Engineering at Harvard. 2 Symmes Street, Roslindale, Mass.

Charles C. Willis, S.B., is with the Sullivan Manufacturing Company, Claremont, N. H. 133 Church Street, Hoosick Falls, Mass.

Horatio S. McDewell, B.S., is an assistant in Engineering 13a and 12b in the Scientific School.

Charles E. Devonshire took a vacation during the summer. He has not yet decided definitely on a position. Roxbury, Mass.

UNDERGRADUATE NOTES.

The following upper-classmen of the Scientific School were employed in engineering last summer:

E. L. Ford was rodman with the Boston Transit Commission. His work was on the congestion of traffic.

E. S. Fuller was transitman with the New York, New Haven, & Hartford Railroad on location work.

O. W. Hartwell was transitman with the Boston Elevated on base-line measurement.

C. E. Nichols was designing reinforced concrete construction with the Eastern Expanded Metal Company.

L. Rome was chainman with the Hudson Company, 6th Avenue Extension, New York City, and rodman on the Erie Railroad, New York Division, Jersey City.

K. DeW. Schwendener was transitman on the B. R. & P. R.R. on construction work.

L. E. Varnam was in the sampling mill of the Garfield Smelting Company.

G. A. McKay was timekeeper with the Foundation Company of New York in New York City on foundations for office buildings, and in Schenectady on foundations for a gas-producer plant for the General Electric Company.

E. L. Lincoln was rodman with the Charles River Basin Commission, Boston, on construction and office work.

E. W. Cook was electrician with the B. F. Sturtevant Company.

E. B. Smith ran a launch on Squam Lake.

W. W. White was employed in the astronomical observatory.

Ernest B. Allen opened an office and contracted for all classes of draughting, also bought and sold automobile parts.

The following men were assistants to Professor Hughes in surveying at the Engineering Camp at Squam Lake: M. T. Rogers, F. W. Swain, H. U. Ransom, P. N. Moore, E. N. Hutchins.

NEWS ITEMS.

"*The Art of Cutting Metals,*" by Frederick W. Taylor, M.E., Sc.D., which was the Presidential address presented at the last annual meeting of The American Society of Mechanical Engineers, has been reprinted and bound in cloth by the Society, price $3.00. This or any other publication of the Society may be had by addressing the Secretary, 29 West 39th Street, New York. It is not necessary to send orders through members. None of the publications of The American Society of Mechanical Engineers are copyrighted.

The Bristol Company are building a new addition to their plant, 53 feet by 170 feet, and three stories high, made necessary by the increased demand for "Bristol's" Recorders and "Bristol's" Patent Steel Belt Lacing. Their Bulletin No. 57, issued in May, contains an account of their new "Bristol's" A.C.-D.C. Recording Voltmeter of the Switchboard Form, which "commend themselves for their simplicity and high character of service performed." H. P. Dennis, M.E., is the author of a little pamphlet on "Plant Economy," which the company are gladly distributing to interested parties. It deals largely with methods of obtaining higher boiler plant efficiency.


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JANUARY, 1908

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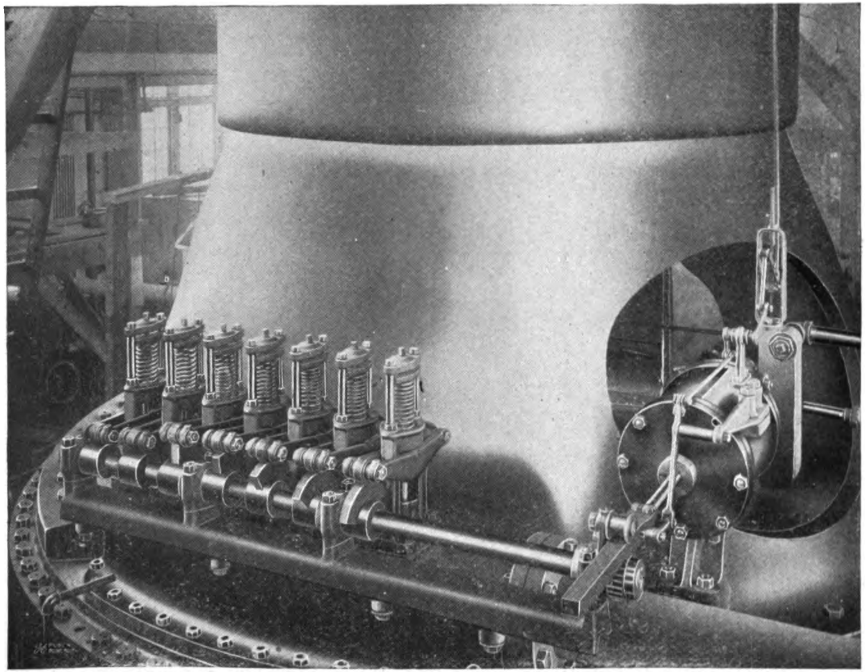
ENGINEERING AND ARCHITECTURE
AT HARVARD UNIVERSITY

Vol. VI TABLE OF CONTENTS No. 4

ENGINEERING NEWS
A Journal of Civil, Mechanical, Mining and Electrical Engineering
220 BROADWAY, NEW YORK
Volume 58
No. 12
$5.00 per year
Single Copies, 15 Cents



Frontispiece (Fig. 6—page 160).

FIG. 6—ONE OF THE TWO VALVE SETS AND THE HYDRAULIC CONTROLLING CYLINDER ON A CURTIS TURBINE.

HARVARD
ENGINEERING JOURNAL

A QUARTERLY

Devoted to the interests of Engineering
and Architecture of Harvard University

VOL. VI JANUARY, 1908 NO. 4

THE SYNCHRONOUS MOTOR.

BY PROFESSOR C. A. ADAMS, S.B., E.E.

The following articles are intended primarily for those who wish to get a thorough understanding of the physical phenomena involved in synchronous motor operation as well as a working theory of the same. It is assumed that the reader is familiar with the structural features of this type of machine, which are to all intents and purposes identical with those of the synchronous alternator.

I.

INTRODUCTION.

The explanations which follow refer specifically to the revolving armature type of machine, although the general line of argument is the same for the revolving field type.

If the field of a synchronous motor be excited with a continuous current, and the armature while stationary be supplied with an alternating current, this latter current will react upon the field in one direction during one-half of a cycle and in the opposite direction during the other half, these alternations of torque or turning moment being much too rapid to allow of any movement of the armature, other than a violent vibration. But if, by some external means, the armature be placed in rotation at synchronous speed, — *i e.* at a speed such that the frequency of the e. m. f. induced by the rotation is the same as that of the impressed e. m. f.,— and if then the current in a given belt of the armature winding is positive when the belt is under a north pole, it will be negative when the same belt comes

under a south pole, and so on, the reaction between this current and the flux from the pole under which it lies being always in the same direction. Thus the machine will continue to run at this synchronous speed* without mechanical aid as long as the turning moment produced by this electromagnetic reaction is just sufficient to balance the counter torque of the load. If on any account the speed slips from exact synchronism, the several belts of armature current will at times be found under poles of such polarity that the torque will be negative and the motor will quickly come to rest.

The means by which the motor torque is automatically adjusted to meet the demands of the load, and the limits beyond which this adjustment cannot take place, will first occupy our attention.

In a continuous current shunt motor, there is a positive belt of current under one pole and a negative belt under the other pole at all times, independently of the speed or position of the armature. The only way of reversing the relative direction of current and flux is to change the relative direction in which the field and armature windings are connected to the supply circuit, or by shifting the brushes. In this type of motor on a constant potential circuit, the flux will be approximately constant, and the torque is thus approximately proportional to the armature current, demand for increased torque being met by an increased current brought about by a slight decrease of speed and counter e. m. f.

The synchronous motor differs from the d. c. shunt motor in several important points. First, the motor must run at synchronous speed or not at all, and this speed is for a given motor dependent upon the frequency of supply and *not* upon the load; second, the relative direction of a belt of armature current, and the flux in which it is found, depends upon the relation between the position of the revolving part of the motor and the phase of the supply current; or upon the relative position of the revolving part of the motor and that of the alternator which supplies the current.

This will be made more clear by referring to the diagram of Fig. 1. The developed armature periphery is represented by the horizontal straight line, and the poles are shown dotted. The density of the magnetic flux across the air gap is assumed to be distributed sinusoidally around the armature periphery, as shown by the curve

b_g. Positive ordinates of the b_g curve designate flux from pole to armature, or downwards, in the diagram; positive ordinates of current or e. m. f. curves, designate currents or e. m. f.'s outwards from the paper, or towards the observer; and positive ordinates of the d curve designate an electromagnetic reaction urging the wire from left to right, in the direction of rotation.

Follow a single armature conductor through the field from left to right. Assuming the speed of rotation to be synchronous and

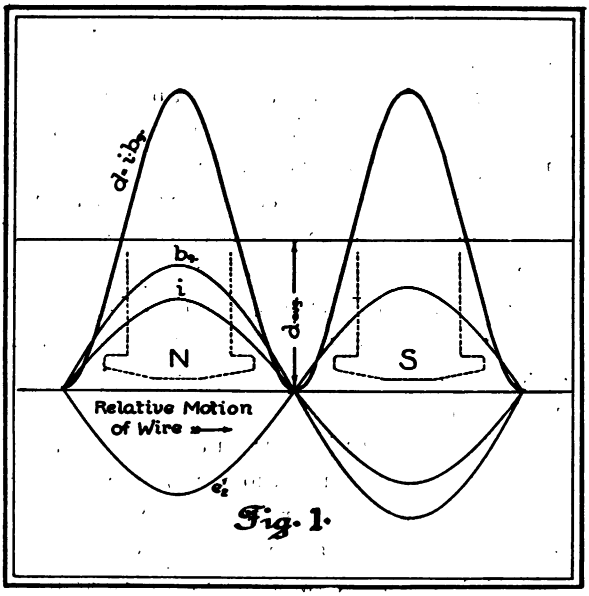


Fig. 1.

therefore constant, the induced e. m. f. will be at each point proportional to the density of the flux at that point and in direction backwards under the north pole; this e. m. f. is represented by the curve e'_2. If now the armature current be sinusoidal, and of such phase that its maximum value occurs when the conductor is in the center of the positive (or north pole) field, its zero value will occur in zero field, and so on, as shown by curve i. The reaction of this current on the field is at each instant proportional to the corresponding current strength and to the strength of the field across which the current lies; it is thus proportional to the product of the corresponding ordinates of the i and the b_g curves, and is represented by the curve d.

The pulsations of torque indicated in this curve are neutralized in a polyphase motor by the overlapping of the torque curves of the other phases, and in the single phase motor are so rapid in proportion to the moment of inertia of the revolving part, that they do not affect the operation appreciably.

It will be observed that since e'_2 is proportional to b_g, ib_g $(=d)$, is proportional to $-i\,e'_2$, and that the power transformed into mechanical form, which at constant speed is proportional to the torque or to d, is thus proportional to $-i\,e'_2$, which is as it should be. The negative sign merely signifies that the electrical power *developed* in the motor is negative; *i.e.* power received rather than delivered.

If now the current phase be shifted back, or the motor armature be boosted ahead slightly, then the maximum current will occur in the conductor after the latter has passed the center of the pole, as shown in Fig. 2. In this case the torque is actually negative for a short part of the cycle, and its average value is considerably less than in the first case. If the phase difference between b_g and i be θ_2, their average product is $B_g\,I\cos\theta_2$ (where B_g and I are the r. m. s. values), which is proportional to $E'_2\,I\cos\theta_2$; *i. e.* the average power transformed into mechanical form.

Thus for a given magnitude of the current its torque producing effect depends upon its phase with respect to the field, and may have any value from a positive maximum to a negative maximum; *e.g.* if θ_2 be greater than 90°, the average torque will be negative and will tend to check the rotation rather than to maintain it. Since for a given current and flux, the torque depends upon $\cos\theta_2$, the latter may be looked upon as the lever arm of the electromagnetic reaction between current and flux. This conception will be developed on a later page.

If the armature is revolving at a speed below synchronism, then even if the maximum current occurs when the conductor is under the center of a pole for one particular half-cycle, the next maximum will occur before the conductor has reached the center of the next pole, and so on until the torque becomes negative, then positive again, and so on, see Fig. 3, where the broken curve shows the variation of the average torque and power transformed.

With this picture of the torque producing mechanism in mind, consider the factors which determine the phase and magnitude of the armature current, upon which the torque depends.

General Vector Diagram.

In order to obtain a fairly simple general solution of this problem, certain assumptions must be made. Consider first the diagram of Fig. 4: *R* represents in magnitude and space phase[1] or direction, the resultant of the field m. m. f. *F* and the armature m. m. f. *A*.

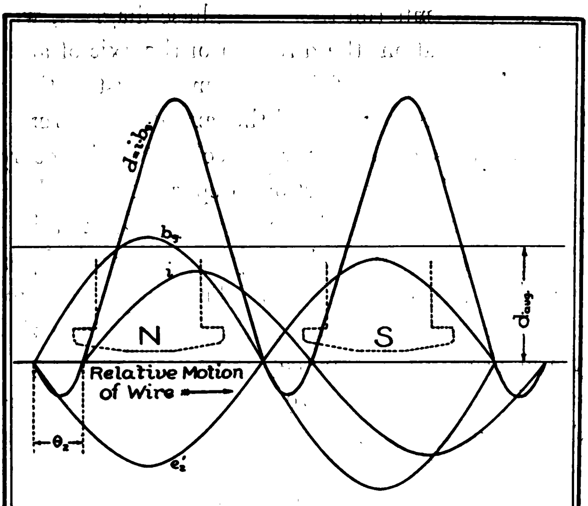


Fig. 2.

The space phase of *F* is its direction reduced to a two-pole equivalent; *i.e.* the direction of the axis of the field poles in two-pole diagram. The space phase of *A* is, for a single phase machine, the average direction of the armature m. m. f. and coincides with the direction of this m. m. f. when the current is a maximum, right-handed or clockwise rotation of the armature being assumed. In a polyphase machine the resultant of the m. m. f.'s of the several armature phases is approximately constant in magnitude and direction

1 A similar analysis for the alternator is given in greater detail in the Harvard Engineering Journal for January, 1903.

for all parts of a revolution. The time phase of the armature current I may also be represented by the direction of A; and by choosing a proper scale of amperes, the vectors I and A may be made identical.

Assuming that the reluctance of the magnetic circuit through the armature and air gap is the same in all radial directions, there will result a flux, Φ, in the same direction as R. The rotation of the armature through this flux will cause to be induced an e. m. f. E'_2 in magnitude proportional to, and in time phase 90° behind, Φ. The vector E'_2 also represents (on the space phase diagram, with right-handed [1] armature rotation) the direction of the axis of an armature coil when the induced e. m. f. is a maximum, just as the vector I represents both the time phase of the armature current and the direction of the axis of an armature coil when its current is a maximum, which is thus the direction or space phase of the armature m. m. f. A. The vector E'_1 drawn equal to E'_2 and in opposite phase, represents that part of the impressed e. m. f. E_1 necessary to balance the induced e. m. f. (E'_2). The impressed e. m. f. (E_1) must then be equal to E'_1 plus the e. m. f. Ir, in phase with I, consumed by the armature resistance, and the e. m. f. Ix, 90° ahead of I, consumed by the leakage reactance of the armature.

The diagram of Fig. 4 gives a fairly complete representation of the relations involved in the operation of the synchronous motor. Two assumptions are involved, however, which should be kept in mind in case of a quantitative analysis: first, it is assumed that the flux Φ is in the same direction as the resultant m. m. f., R; but as the reluctance of the magnetic circuit through the armature is least in the direction of F and very much larger at right angles thereto, the flux will tend to lie inside of R, *i. e.* on the side towards F: second, F is taken as the total m. m. f. of the field coils per complete magnetic circuit; but a part of F is consumed by the reluctance of the field cores and yoke, and is thus not available to compound with A in the armature space. The errors due to these two

1 It will be observed that the right-handed or clockwise armature rotation here assumed for the space phase interpretation of the diagram corresponds to the customary left-handed vector rotation in the time phase diagram. In the case of a revolving field type of machine, the field must revolve left-handedly, in order to give the same relative motion between armature and field.

assumptions partly neutralize each other as far as the direction of Φ is concerned, since the first throws it too far out and the second tends to bring it back.

Power and Torque.

The power in watts per phase delivered to the motor is $P_1 = E_1 I \cos \theta_1$, of which $I^2 r$ watts are consumed by resistance, and the remainder $P_2 = E'_1 I \cos \theta'$ is transformed into mechanical form. This latter includes the core and friction losses as well as the output, but in order to simplify the problem, it will be convenient to refer to P_2 as the output.

Since $E'_2 = E'_1$ and $\theta_2 = \theta'$ (see Fig. 2), $P_2 = E'_2 I \cos \theta_2$, which is as it should be. Moreover, at constant speed, the torque is proportional to P_2, and as E'_2 is proportional to Φ, the torque is proportional to $\Phi\ I \cos \theta_2$. This again brings out one of the chief points of difference between continuous and alternating current motors, the fact that in the latter the torque depends not only upon the current and the flux, but upon their relative space phase.

Another explanation of this relation is obtained by considering the armature as an electromagnet lying across a magnetic field (see Fig. 5). The direction and magnitude of this field are indicated by the vector Φ; the direction and strength of the armature polarity are indicated by the vector A; and the turning moment or torque is therefore proportional to the product of Φ and A (or I) and the arm of the couple, which is proportional to the sine of the angle β between Φ and A; but $\sin \beta = \cos \theta' = \cos \theta_2$. Thus the torque is proportional to $I \cos \theta_2$, as above, and $\cos \theta_2$ appears again in a more tangible form as a measure of the arm of the torque couple, or of the torque-producing effect of the current.

Variation of Load.

Imagine the load to be suddenly increased while the excitation F remains constant. If the increase of load is not abnormal, the corresponding increase of current will be moderate, and the increase in the impedance drop, Iz, between E_1 and E'_1 will be small. In general E'_1 and therefore Φ and R will be somewhat smaller. It is thus evident that $I \cos \theta'$ must increase slightly more than did

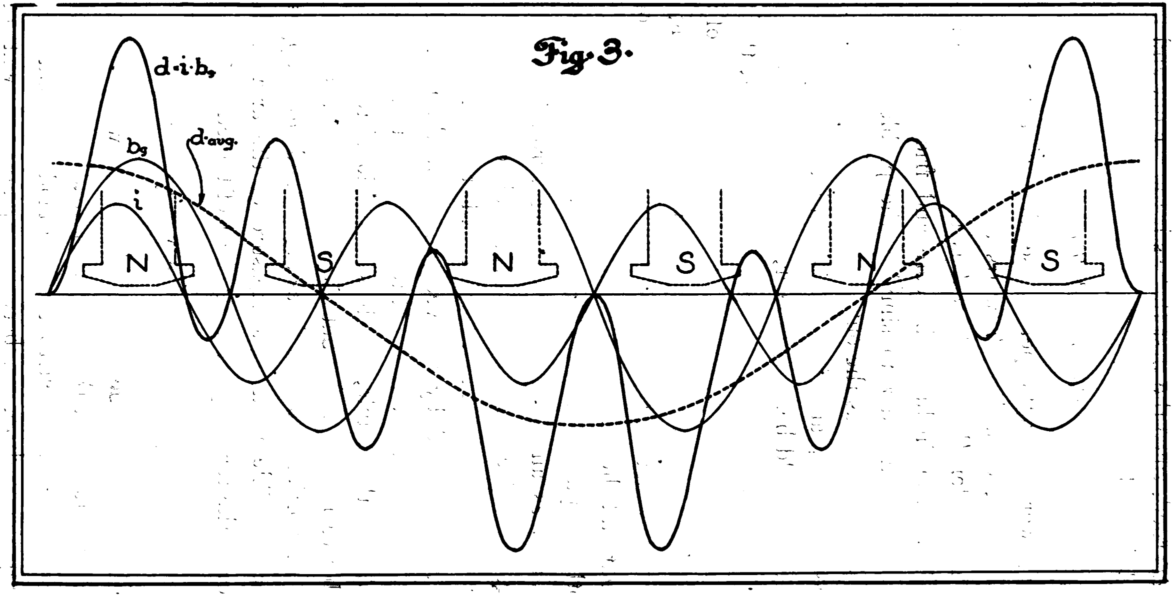


Fig. 3.
d·i·b,
b₅
d·avg.
i
N
S
N
S
N
S

the load, and that the point B must move upward in the diagram, accompanied by an increase of the angle ϕ, the triangle AFR remaining closed.

The order of these changes is as follows: at the instant of increase of load, the demand for power will be greater than the supply and the armature will begin to slow down or lag in the field, i. e. the maximum value of the impressed e. m. f. will occur before the axis of the armature coil has reached the position E_1 of Fig. 4. Thus the vector E_1 will shift to the left with respect to F (the axis of the field magnets), and the resulting increase in the impedance e. m. f. Iz, will indicate a larger current. When the balance is reached, $E'_1 I \cos \theta'$ will have increased to meet the demands of the load as shown in the light line diagram of Fig. 4. Although the armature has sagged back in the field by a small angle, it is still running at synchronous speed. Any farther lag would cause more current to flow and a larger torque to be developed than is demanded by the load, which would cause the armature to accelerate and gain on the armature of the supply alternator until equilibrium is again restored. Thus the power absorbed from the line is automatically adjusted to meet the demands of an increased load by a lagging back of the motor armature with respect to that of the generator (*i. e.* by an increase of the angle ϕ) and by a resulting increase of current which reacts upon the nearly constant flux to produce the needed increase of torque. Meantime θ' has also changed and the lever arm ($\cos \theta'$) of the current reaction is altered accordingly; but within the normal range of operation this change is small as compared with that of the current.

In other words, the adjustment is brought about by a change of space phase of the armature current rather than by a change of speed.

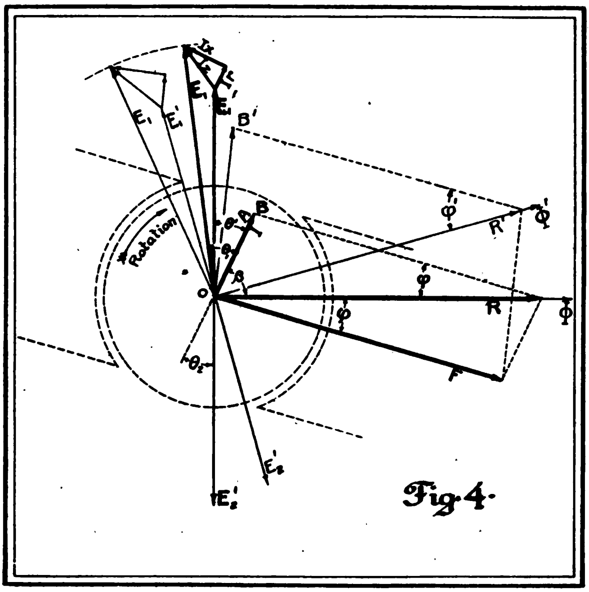
An increase of load beyond a certain point will cause a decrease in the flux Φ and a decrease in the lever arm of the torque couple, such as to more than neutralize the effect of the increased current. This point will be made more clear in connection with some of the other diagrams.

But even this diagram with its approximations is too complex to be of service in getting a clear bird's eye view of synchronous

motor operation, although it is an excellent starting point for further approximations, and will prove very useful for reference purposes.

Approximate Diagram "A," Fig. 6.

Although this diagram involves such crude approximations, it is nevertheless very helpful in giving a rough general picture of the operation of the synchronous motor. Neglect r and x; then $E_1 = E'_1 = E'_2$; Φ and R will be constant for constant impressed



e. m. f.; $P_1 = P_2 = E_1 I \cos \theta_1$; and at constant speed, the torque is proportional to P_2 and therefore to $I \cos \theta_1$ ($= \overline{OB_o}$), since E_1 is constant.

Thus if the excitation (F) and the output (P_2) are fixed, the point B is fixed, since it must lie on the circle about D with radius F, and must also lie on the horizontal line $\overline{PP}$, such that $\overline{OB_o} = P_2 \div E_1$. Or the case may be stated as follows: if E_1 is constant and fixed, there must be a constant flux Φ, the cutting of which at synchronous speed by the armature conductors will generate an e. m. f. E'_2 ($= -E'_1 = -E_1$), and the net or resultant m. m. f., R (of field and armature), must be such as to produce this flux, and must therefore

be constant. Then for a given excitation F, the point B must lie on a circle of radius F, with center at D, and the current (or armature m. m. f.) vector $\overline{OB}$ must have a power or torque component $\overline{OB_o}$, such as to supply the demands of the load. The point B must therefore be the intersection of the horizontal line through B_o and the circle mentioned above.

Variation of Load.

If now the load be increased, the point B will fall back (clockwise) to some point, B', such that the corresponding torque current OB'_o will be sufficient to supply the increased torque. The physical interpretation of this change is as follows: at the instant of increase of load, the power received from the line is insufficient to meet the increased demand, and the armature begins to slow down or lag in the field, i. e. the maximum value of the impressed e. m. f. will occur before the axis of the coil has reached the position of E_1 (Fig. 6). Thus E_1 and therefore Φ and R will be rotated counterclockwise with respect to F; but as E_1 is usually the fixed quantity, and as its direction may be taken as that of the axis of the armature of the supply alternator when e_1 is a maximum, it will be more convenient and natural to take the E_1 vector as the fixed line of the diagram or the basis of phase reference, and to obtain the same relative change by rotating F in the opposite or clockwise direction.[1] F and A are then the only variables, since Φ and R are fixed by E_1.

As the load is still farther increased, the motor lags more, the vector F swings farther to the right, the angle ϕ increases and the current increases, but the torque component of the current, $\overline{OB_o}$, does not increase as rapidly as the current; in fact, as F swings into the vertical position, the torque component approaches a maximum value, and beyond this actually decreases; *i. e.* the lever arm ($\sin \beta = \cos \theta'$) of the couple decreases more rapidly than the force $A\Phi$ increases, see Fig. 5.

The angle ϕ (Fig. 6) represents the difference in space phase between the armature of the supply generator and that of the motor, or their difference in angular position reduced to a two-pole basis.

1 In the case of a revolving field motor, the field rotation will be left-handed or counterclockwise, and a lag of this rotation will mean a relative clockwise rotation of the field structure and of F, just as in the diagram.

For any given load, this phase difference remains constant, and the two machines run at exactly the same speed. An increase of load causes the motor to lag a little more, with a corresponding increase in ϕ. If the load be removed, the motor will accelerate temporarily until the angle ϕ has closed up to a point such that the corresponding power current, $\overline{OB_o}$, is just sufficient to supply the friction and core losses.

If while still connected to the supply circuit, the motor be mechanically driven by a prime mover at exactly synchronous speed, with the angle ϕ at zero, no power will be received from the line, and the only power received mechanically will be that necessary for friction and core losses. If then the prime mover be urged ahead slightly, ϕ will become negative, and the armature current will swing around more nearly into phase with E'_2. Thus the electrical power received from the line becomes negative, and the power developed electrically in the armature becomes positive; *i. e.* the motor is acting as a generator, delivering power back to the line, the source of this power being the prime mover. Moreover, if it is attempted to urge the prime mover to a speed higher than synchronism, ϕ will increase negatively, and the generator or backward torque will increase to several times the full load value before the machine will break from the synchronous speed, the tendency of the electrical connection between the motor and the line being to hold the former to synchronous speed, whether it is receiving or delivering electrical power. The electrical connection acts like an elastic coupling between the motor and the supply alternator.

Thus the relative space phase (ϕ) between motor and supply alternator determines the amount of power received by the motor from the alternator; *i. e.* ϕ is the automatic throttle valve and takes the place of speed variation in the continuous current shunt motor.

The angle ϕ will be called positive above the horizontal in Fig. 6, *i. e.* for motor operation; and negative below the horizontal for generator operation. Thus when the point B lies anywhere above the line $\overline{OD}$, the machine is receiving power from the line, and for points below $\overline{OD}$, it is delivering power to the line, the line $\overline{OD}$ being the zero power line.

Variation of Exciting Current.

Referring again to Fig. 6, imagine the field excitation F to be increased without change of load. The torque current OB_0 must remain unchanged; therefore the point B must move horizontally along the line $\overline{PP}$ of constant power and torque, to some point B'', corresponding to the new excitation. The armature current has thus changed from a lagging to a leading current, which change may be explained as follows. Divide the armature m. m. f. A into two components, one in phase with E_1 and the other in quadrature

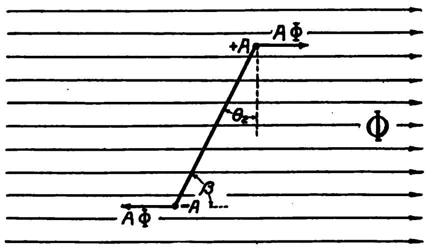


Fig. 5.

therewith. The former is the torque component already considered, and the latter, in line with Φ and R, is a magnetizing or demagnetizing component, according as the current lags or leads.[1] Thus since the total resultant m. m. f. R must remain constant, the armature current assumes such a phase and magnitude that it supplies the necessary torque component and also a quadrature component of sufficient magnitude to make up for any deficiency in the field excitation.

1 A current in the motor is said to be lagging when it is behind the impressed e. m. f. but a quadrature component 90° behind the impressed e .m. f. is 90° ahead of the induced e. m. f. Thus a quadrature component is magnetizing when ahead of the induced e. m. f. just as in the alternating current generator, motor or transformer, and is demagnetizing when behind the induced e. m. f., *i. e.* ahead of the impressed e. m. f. of the synchronous motor.

If it were possible, practically, the number of "periods" would be made so small that free expansion would be reduced to a minimum; but for a satisfactory speed regulation long periods are not permissible. It appears, therefore, that unless the periodicity can be made low, the economy at light loads is no great improvement on the method of plain throttling. A very important feature of this method, however, should not be overlooked. This is the advantage of having a valve mech-

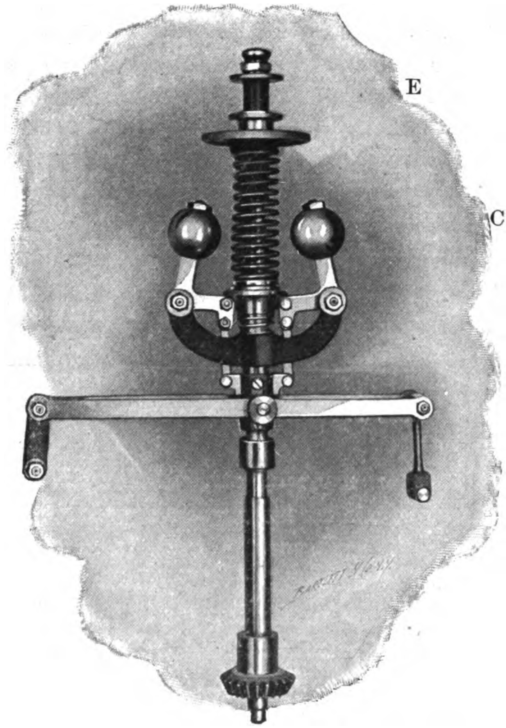


FIG. 8. GOVERNOR OF A WESTINGHOUSE-PARSONS TURBINE.

anism which is *constantly moving*, precluding the possibility of "sticky" valves.

The time required for the steam entrapped in the casing when the valves are closed to drop in pressure by a given amount can be calculated very simply as follows:

Let

W_1 = weight of steam (pounds) entrapped when the valves are closed;

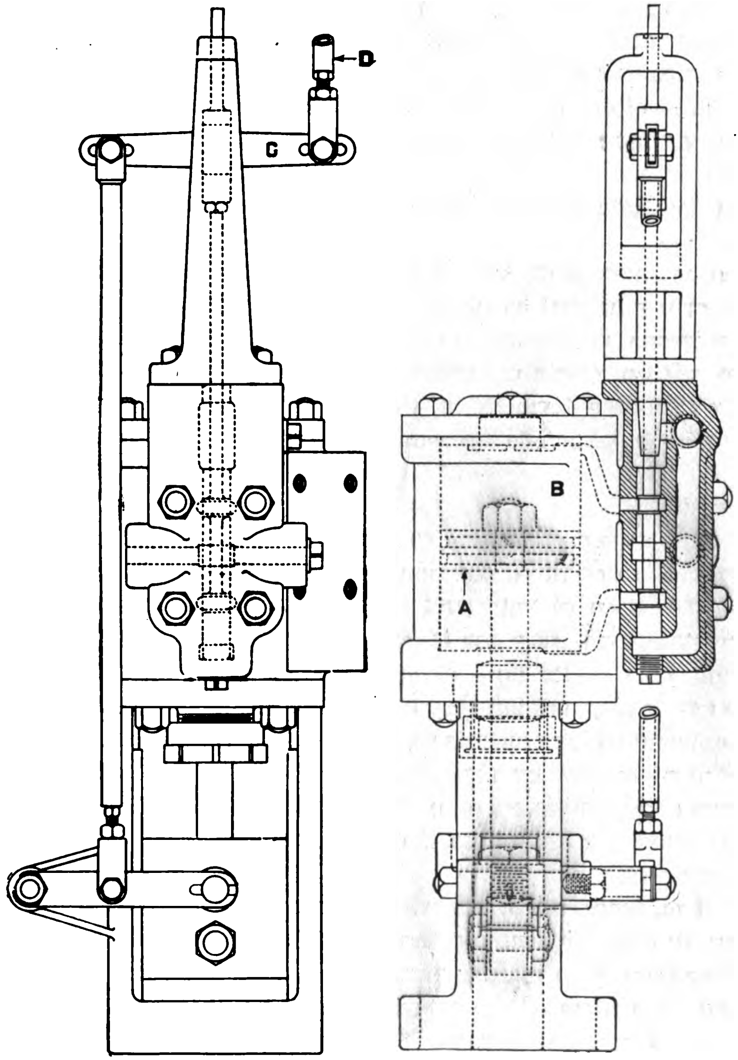


FIG. 5. THE HYDRAULIC OPERATING MECHANISM FOR VALVES OF A CURTIS TURBINE.

directly on the valves, opening and closing them according to the demands of the load. Because this device has a very slow motion, it has the advantage of being independent of lubrication for its successful operation.

Governing by Varying the Time of Admission. — Governing by periodic admission or by "blasts" was invented by

but since

$$P_1 V_1 = K \text{ and}$$

$$C = \frac{W'}{P_1}$$

$$t = \frac{W_1}{W^1} \log_e \left(\frac{P_1}{P_2}\right)$$

If, for example, $W' = 2\frac{1}{4}$ pounds of steam per second, $W_1 = \frac{3}{4}$ pound, and $P = 165$ pounds absolute pressure, quantities corresponding to a periodicity of one blast in about thirty revolutions, the time required for the average pressure in the casing to fall to 100 pounds is $\frac{3}{4 \times 2.25} \log_e \frac{165}{100} = .159$ second. The time required for steam at 165 pounds absolute to fall

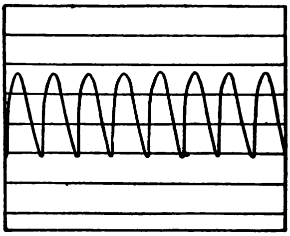


FIG. 9. PRESSURE VARIATION IN A PARSONS TURBINE.

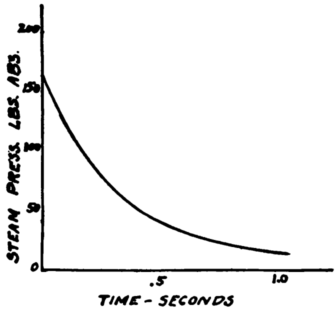


FIG. 10. TIME REQUIRED FOR PRESSURE VARIATIONS IN A PARSONS TURBINE.

to various other pressures, according to Jude, is shown in Fig. 10.

Usually the no-load pressure varies from about 25 to 50 pounds absolute, when, according to the curve, the time required to reach this pressure without throttling is about .4 to .8 second; and as the load is increased, correspondingly shorter times.

By-pass Governors. — In all turbines the area of the steam passages increases in going from the high-pressure end to the exhaust. Consequently it is possible to admit a large quantity of high-pressure steam to a turbine by admitting it into the middle stages, in addition to the steam coming through the high-pressure nozzles. By this method an auxiliary poppet

valve opens slowly and admits high-presure steam directly into the low-pressure stages of the turbine. As the steam entering through the by-pass valve acts on fewer rows of blades than the steam admitted under normal conditions, obviously the method is uneconomical and is, therefore, used only for a large overload. When a by-pass valve is used, the turbine is usually designed to be just large enough to carry its normal full load, where, of course, it is most economical; and, for overload, it is expected that the efficiency is considerably reduced.

If, on the other hand, turbines are designed to take a large overload without a by-pass, the turbine must be of correspondingly greater capacity than the full rating indicates. The best economy of steam will then be at the *highest output,* and not quite so good at three-fourths load and full load.

All the makers of Parsons and Rateau turbines use by-pass valves. The Westinghouse turbine has by-pass overload valves

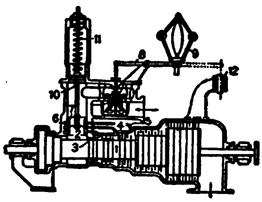


FIG. 11. BY-PASS GOVERNING ARRANGEMENT.

under the control of the governor, so that they automatically open when an overload comes on; but on most turbines by-pass valves are opened by hand.

Overload economy is not usually of great importance, so that, practically, it is considered more feasible to use overload valves than to install additional turbines. In turbines of the Curtis type, which can be made to take a large overload with the addition of only a few extra nozzles without increasing the other dimensions, by-pass valves for overload have no advantages. In Parsons turbines, as anticipated in the design, there is a decided falling off in speed when the overload valves open.

A by-pass governor is shown in Fig. 11, which is a diagrammatic sketch showing the method of admitting high-pressure steam to the low-pressure stages of a Parsons turbine. This particular device is due to Brown-Boveri & Co. This de-

sign shows the by-pass method applied to an exceptionally well-made turbine, much used in Europe. The by-pass ports open only at overload, and the speed is regulated for small fluctuations by the throttling method. In the figure the centrifugal governor is marked 9, and operates a balanced throttle valve connected to the lever 8. The by-pass valve 7, on the other hand, is operated by the pressure on the piston 10. Since this piston and the by-pass valve are on the same valve stem, they are raised or lowered together, according as the pressure in the steam chest below the piston 10 is high or low. With a high pressure the piston rises, lifting with it the valve 7, thus uncovering the ports, shown on one side of the turbine at 6, which admit steam through the pipes 3, 4, and 5 to different parts of the turbine casing. Obviously, there is a considerable change in the power developed immediately after the steam is admitted to one of the pipes 3, 4, or 5; and the consequent fluctuation in speed is taken care of by the throttling governor 9, or by an electrical solenoid governor indicated at 12.

Experimental Data Concerning Governing. — Something should be said about the experimental results at hand concerning the different methods of governing. Curves illustrating the effects of throttling have been shown in Fig. 1, but a better comparison can be made from the following table: *

		Fraction of Load		
	Kw.	½	¾	*Full*
Curtis	500	51.7	76.2	100
Curtis	600	52.4	76.5	100
De Laval	20	68.0	82.0	100
De Laval	† 200	52.3	76.2	100
C. A. Parsons Company	500	56.0	78.0	100
Rateau	500	55.0	77.2	100
Westinghouse-Parsons	400	57.0	78.5	100
Westinghouse-Parsons	1,250	57.3	78.5	100
Zoelly	350	58.8	80.3	100

Fractions of load given at the top of each column refer to fractions of the most efficient load. Steam consumption at

* From *Mechanical Engineer*, January 20, 1906.
† Governed by cutting out nozzles.

the different loads is expressed as a percentage compared with the steam consumption at the most economical load for each particular machine. In other words, if the economy of any of these turbines were as good at half load as at full load, we should have in the table under the column for one-half load 50 per cent, etc.

Results in this table must be used guardedly and not confused with steam consumption. For example, the De Laval 200 kw. turbine appears to such good advantage here because the system of governing used for these tests was nearly ideal. Full load steam consumption, on the other hand, was very high compared with any other make of turbine in the list.

The Zoelly, Rateau, and the 20 kw. De Laval turbines used simple throttling governors.

The Curtis and the 200 kw. De Laval turbines were governed by varying the number of nozzles to suit the load. The original Parsons and Westinghouse-Parsons turbines used the "blast" governor. These data lead to the conclusion that the Curtis and the experimental De Laval (200 kw.) give the best results as regards the method of governing.

Sufficient data are not available of the performance of Wilkinson and Allis-Chalmers steam turbines. The latter is a Parsons type with a plain throttling governor, while the former is governed by a complex method, equivalent to "cutting out nozzles," and resembling, in its method of action, the Westinghouse-Parsons "by-pass" governing for overloads, and is akin to a variable cut-off, with a simultaneous throttling in the reciprocating engine. Considering only these two new turbines, the Wilkinson should give the better relative results at light loads.

For Figs. 4, 5 and 6 we are indebted to the General Electric Company, and for Figs. 8 and 9 to Westinghouse, Church, Kerr & Co.

THE IMPROVEMENT OF THE UPPER MYSTIC RIVER AND ALEWIFE BROOK BY MEANS OF TIDE GATES AND LARGE DRAINAGE CHANNELS.

BY J. R. RABLIN,

CHIEF ENGINEER OF THE METROPOLITAN PARK COMMISSION.

The report of the preliminary Metropolitan Park Commission to the legislature of 1893 suggested, through the accompanying report and plan of Charles Eliot, its landscape architect, a river road and parkway drive from Winchester along Aberjona River and Mystic Lake and Mystic River to and across the marshes of Malden River, and through a portion of the cities of Everett and Chelsea across Snake Creek and Revere marshes to Revere Beach. Since then the permanent Board of Metropolitan Park Commissioners has been from year to year gradually acquiring land for such river road and parkway, and extending the construction as funds became available.

Revere Beach Parkway is substantially completed to Fellsway, in the part of Medford known as Wellington. From that point to High Street in Medford, at the foot of Lower Mystic Lake, necessary land for construction of the river road has been acquired, and from High Street a road has been constructed through a park-like reservation along Mystic Lake and Aberjona River to Winchester, where a short piece of parkway connects with the westerly side of Middlesex Fells. The land along Mystic River was acquired Nov. 29, 1899, under a joint agreement by which the city of Medford acquired the land from Middlesex Fells Parkway to a point near Cradock Bridge, upon the understanding that the Metropolitan Park Commission would in due time construct the roadway thereon, and would also acquire the land and build the roadway from Cradock Bridge to Mystic Lake.

In making more detailed plans for this work, Messrs. Olmsted Brothers, landscape architects, suggested that a dam be built with weirs and lock near Cradock Bridge, and that the water above be held at a permanent level just below the

grade of the marshes. In 1903, funds having become immediately available, the commission required of its engineering department detailed plans and specifications for carrying out the general plans of the landscape advisers. Attention was then called to a special act, Chapter 327 of the Acts of 1903, which authorized the towns of Arlington and Belmont and the cities of Cambridge and Somerville to unite in improving the sanitary condition of Alewife Brook and meadows, and for this purpose to place tide gates at the outlet of the brook into Mystic River. The possibility of conflict and of waste of money at once led the Metropolitan Park Commission to seek eminent engineering and scientific advice wholly outside of its accustomed engineers and advisers, and to suspend operations along Mystic River pending such disinterested examination and report, and to ask the cities and towns interested to also suspend operations in the neighborhood of Alewife Brook. As a further precaution, the commission joined with the cities and towns to secure from the legislature the enactment of Chapter 445 of the Acts of 1904, requiring assent of the State Board of Health to a dam at Cradock Bridge.

Mr. John R. Freeman, the eminent engineer, upon whose report the legislation authorizing a dam across Charles River to replace Craigie Bridge was based, conducted the investigations upon Mystic River and Alewife Brook, which investigations showed that the interests of the community would be most cheaply and most promptly served if sanitary improvements of Alewife Brook and Mystic River improvements were carried on together, and that each might serve the other and divide the expense. Cambridge and the other cities and towns would be made more free from malaria and gain in the increased value of lands, which could not otherwise be improved except at a prohibitive cost, and if the land needed for the sanitary improvement could also be used for a parkway, it would add still further to the general welfare.

As a result of the investigations, Mr. Freeman made the following recommendations:

Drain the marshes and construct large tide gates and freshet sluices at Cradock Bridge, such that the water level will ordinarily stand at elevation 7.0, the drainage to be done by means

of enlarged open channels. Fill small stagnant pools, and execute such ditching and filling of low areas as will prevent breeding-places for mosquitoes.

Utilize Spy Pond and Lower Mystic Lake as reservoirs to assist in holding the clean upland storm water during the hours while the harbor tide is above this basin level, and also for holding back the height of extreme freshets. Divert Wellington Brook above Wellington Street into Little Pond, and provide a controlling sluice and weir adapted to passage of small boats at the outlet of Little Pond (and possibly another at Lower Mystic Lake), so that the cleaner upland water, that which now enters Spy Pond, may be used to flush out from Alewife Brook the storm overflow of sewage.

Cleanse Alewife Brook by excluding present foul tannery refuse; also by diverting other pollution into the sewers. Extend certain of the storm overflows from Cambridge sewers to a point near Massachusetts Avenue, where there is more current than at the present location of the outfalls. Fill or partially fill and drain into the brooks the clay pits which are no longer in operation, and the pockets between graded streets near the clay pits in which the water now stands and forms breeding-places for mosquitoes.

Prescribe heights limiting the future development of these marshes, so that cellar bottoms shall not be built lower than Grade 13, nor street surfaces (other than park roads) built lower than Grade 16, and that low pockets, or depressions in the ground formed between streets or other embankments, shall have proper drainage channels and valves leading to the main channel. In brief, take all reasonable means to maintain good surface drainage and exterminate mosquitoes.

Combine the drainage channel with a parkway development.

He also stated in his report that the Metropolitan Park Commission might with safety and consideration for all interests at once build tide gates and weirs in the neighborhood of Cradock Bridge, and roads along the Mystic River, and improve the connection with Mystic Lower Lake; and the other parties interested might, whenever they were ready, continue the work in and along Alewife Brook and the marshes above, and that the work of the Metropolitan Park Commission would not

hamper Arlington, Belmont, Cambridge, and Somerville from proceeding under Chapter 327 of the Acts of 1903, but, on the contrary, would assist them in any feasible plan which they might have devised, and would reduce the expense to them of satisfactory sanitation.

In May, 1906, the State Board of Health made a report to the legislature of its investigations made under Chapter 445 of the Acts of 1904. The recommendations of this report coincided practically with those of Mr. Freeman, and it also stated that, if the proposed dam should be built at Cradock Bridge, with an ample channel excavated from the dam up to the mouth of Alewife Brook, it would render unnecessary a dam at the mouth of Alewife Brook and would be not only consistent with the improvements and purification of Mystic River and Alewife Brook, but would be a very important step taken toward such improvement.

Mr. Freeman submitted with his recommendation an outline design for the tide-gate structure at Cradock Bridge, which was worked out to provide larger waterways through it than are found in the permanent structure of Cradock Bridge. They provide for the minimum fluctuation in water level and are designed to work automatically without attendance, save that required occasionally to raise one or more gates in time of greatest freshets, and this even need not be done until some hours after the heaviest rainstorm has given ample warning. The depth of the sheet of water flowing over the weirs with the ordinary summer flow of 0.50 cubic feet per second per square mile, or 23 cubic feet per second in all, would be a little less than 1 inch and a rise during the six hours of full tide, while the outflow is interrupted, would be a little less than 2 inches. A lock is provided, through which such ordinary boating as can now pass through Cradock Bridge can pass through the lower river to the portion above the tide gates.

This sketch has been developed and detail plans prepared by the engineering department of the Metropolitan Park Commission, and a contract has been made for the construction of a portion of the necessary structures.

The work consists of building river walls, boat lock, canoe runway, weirs, tide gates, and sluices; also an additional span

to Cradock Bridge for the passage of boats, the other openings being necessary for the outflow of the gates.

This work is to be built entirely of reinforced concrete, with the movable parts of iron or wood. The work is now in progress, and it is expected that it will be completed some time next summer.

A large portion of the work of widening and deepening the channel of the Mystic River from Mystic lakes at High Street to Cradock Bridge, Main Street, Medford, has already been done, the material obtained from the excavation having been used in building to subgrade the proposed drives along the river.

By an act of the legislature, Chapter 529 of the Acts of 1906, authority was given for the expenditure of $100,000 for the sanitary improvements of Alewife Brook, the work to be done by the Metropolitan Park Commission.

Upon more careful estimates of the cost of this work, it was determined that the amount authorized would be insufficient, and the former act was amended by Chapter 529 of the Acts of 1907, making the amount $125,000.

The preliminary work incidental to carrying out the provisions of this act is now in progress, and when this work of sanitary improvement of Alewife Brook and the work being done by the Metropolitan Park Commission in the Mystic River is completed, the public health of the whole section of the Metropolitan District which will be drained by these streams will be greatly benefited. Also, the establishment of a basin with permanent water level, to be used for boating and canoeing, and bordered by park drives, will make a beautiful river park reservation for the recreation and enjoyment of the general public.

HARVARD ENGINEERING JOURNAL.

A QUARTERLY

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY.

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.

Subscription Rates.

Per year, in advance	$1.00
Single copies	.35

Address all communications:—

HARVARD ENGINEERING JOURNAL,
Room 218. Pierce Hall,
Cambridge, Mass.

Entered at the Post Office, Boston, Mass., as second-class mail matter June 5, 1902.

EDITORIAL.

It is to be regretted that an unexpected delay has prevented the publication in this issue of the second part of the article on the New York Subway, begun in the November number. It is to be hoped that this very interesting and instructive article may be completed in the next issue of the JOURNAL.

We wish to call special attention to the notice, printed elsewhere in this paper, concerning the Engineering Society dinner to be held some time in March. This dinner has come to be

an annual affair and is looked forward to by the undergraduates, as it gives them an opportunity to meet some of the men who have gone into engineering work. It ought likewise to appeal to the graduates, as giving them an opportunity to return to Cambridge for a few days, to renew their college life, and to meet some of the men who, like themselves, will some day be part of the ever-increasing body of engineers. We trust that a very large number of our graduates will plan to be present at the dinner, and that they will come ready to meet the undergraduates enthusiastically and to give them the encouragement that will make them work the harder in preparation for their future profession. It may seem that such encouragement is a little thing, but it is always appreciated.

The JOURNAL, while published by an undergraduate body, is perhaps of greater interest to the graduates of the University than to those who are now here. This being the case, we are always glad to receive suggestions of any sort from our predecessors and invite honest criticism. We should also be pleased to receive articles from graduates who are so placed that they can prepare articles of interest to our readers, or to be informed of other engineers who, although not graduates of the University, would be willing to write for us. It is only by coöperation that the paper can be so improved as to keep pace with the rapid improvement in all branches of the engineering department.

CIVIL ENGINEERING CLUB.

The December meeting of the club was most informal and so, particularly interesting. Professors Johnson and Hughes were present, the former giving a short talk on the Jungfrau railroad in Switzerland, and the latter relating some of his experiences on construction work in the South. The informal way in which the meeting was conducted made it especially valuable to those present.

On Wednesday evening, Jan. 8, Mr. E. S. Larned, civil engineer, of Boston, gave a talk upon "Cement Testing and Concrete Blocks." At the conclusion of his address, the topic was opened to discussion, and much useful knowledge gained thereby.

HARVARD MECHANICAL CLUB.

The last meeting of the Harvard Mechanical Club was held in Hollis 14 on the evening of Dec. 9, 1907, twenty-five members and Professors Hollis and Kennelly being present.

Mr. W. J. Kennedy of the Edison Electric Illuminating Company of Boston, who was to have spoken at the previous meeting, but who was unable, because of an accident, so to do, was present informally as the speaker of the evening. Mr. Kennedy spoke on "The Practical Management of a Steam Turbine Plant" and gave many of the smaller details of such work in a manner so clear as to be understood by all. The talk was illustrated by means of blue-prints.

At the close of the discussion a vote of thanks was extended to Mr. Kennedy and adjournment was taken to the enjoyment of the usual refreshments.

ENGINEERING SOCIETY.

The annual dinner of the Engineering Society will be held in the Harvard Union during the latter part of March, probably on March 21 or 28. Saturday evening has been decided upon as the most convenient one for graduates who wish to attend. Last year the dinner was a great success, 145 men being present, 40 of whom were graduates. This year the dinner is to be held in conjunction with the graduate society of Harvard engineers, and everything points towards a larger and more enthusiastic gathering. Graduates will receive circulars giving the time of the dinner and a list of speakers, and it is hoped that many of them will be able to be present.

On Dec. 12, 1907, Mr. T. O. Barnard of the Babcock & Wilcox Company gave a very interesting talk on "Boilers." He pointed out the good and weak points of different types and illustrated his talk by stereopticon slides.

Mr. Thomas MacKeller, president of the New England Foundation Company, addressed the society on Jan. 15, in Pierce Hall, with an illustrated talk on "Concrete Piles." For the February meeting of the society, Mr. Alexander S. Greene, vice-president of the Waterproofing Company of New York, will give a talk on the "Waterproofing of Masonry Structures." This lecture will come on Feb. 19 and will also be illustrated.

ELECTRICAL CLUB.

The first meeting of the year, on Dec. 4, 1907, took the form of an informal gathering at Prof. C. A. Adams' house. The chief idea of the meeting was to get the new members in touch with the old, and to have a general good time. Thanks to Mr. and Mrs. Adams, this idea was realized, and every one had a very pleasant evening. Prof. A. E. Kennelly spoke informally on "High-tension Transmission in Switzerland" and gave an interesting account of his recent visit there. Professor Adams spoke briefly on the choosing of a profession, referring principally to the requirements of an engineer.

The January meeting was held on Jan. 9, 1908, at Pierce Hall, where Prof. W. L. Puffer, formerly of M. I. T., and at present the chairman of the Boston branch of the A. I. E. E., spoke on "Illumination." Instead of speaking on the subject from a purely engineering point of view, he referred more to the incidents and difficulties which an illuminating engineer has to contend with in dealing with human nature apart from the theoretical requirements. Refreshments were served.

GRADUATE NOTES.

R. H. Harris, A.B., S.B., '07, is with the Chase-Shawmut Company, a Stone & Webster Company in Newburyport, Mass. He was formerly in the statistics department in Boston.

C. B. Lewis, A.B., S.B., '07, is now with the Indianapolis Water Company at Indianapolis, Ind.

P. Portal, '07, is chief inspector of the construction of a Telford macadam highway in Cuba.

Wm. B. Updegraff, who was assistant in Engineering 3A in 1903-04, has resigned his position with the Lake Torpedo Company of Bridgeport, Conn., and will be identified as mechanical engineer with the Harlem Contracting Company, 201st Street and Harlem River, New York City.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